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THESIS

The Effects of Oil Contamination on
the Nucleate Pool-Boiling Behavior
of R-114 from Enhanced Surfaces

by

Lloyd M. Sawyer, Jr.

June 1986

Thesis Advisor: P. J. Marto

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The Effect of Oil Contamination on the Nucleate Pool-Boiling Performance of R-114 from Enhanced Surfaces

by

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Lieutenant Commander, United States Navy
B.S. Naval Architecture, United States Naval Academy, 1974

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The external nucleate pool-boiling heat-transfer coefficient of both smooth and enhanced horizontal tubes in R-114-oil mixtures (0 to 10 mass percent oil) were measured for heat fluxes from 1 to 91 kW/m^2 at a saturation temperature of 2.2 C. The enhanced tubes tested were a Wieland GEWA-T finned tube containing 1.02 fins/mm, a Hitachi Thermoexcel-E and a Hitachi Thermoexcel-HE tube. The Thermoexcel-E and -HE tubes with their re-entrant cavity designs were found to improve the heat-transfer coefficient over the smooth tube value at a constant heat flux by a factor of approximately 7 in oil-free R-114, while the GEWA-T tube improved the coefficient by a factor of about 4. While all of the tubes showed a generally decreasing performance with the presence of oil, the GEWA-T tube resulted in the minimum reduction. This tube showed up to 20% and 35% reduction (compared to the oil-free case) at 3 percent and 10 percent oil, respectively. The Thermoexcel-E and Thermoexcel-HE tubes showed performance reductions of up to 40% and 60%, respectively, with 3 percent oil. At a practical heat flux of about 30 kW/m^2 with 3 percent oil, the GEWA-T, Thermoexcel-E and Thermoexcel-HE tubes outperformed the smooth tube by factors of 4.8, 4.6 and 4.0, respectively.

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I. INTRODUCTION

A. BACKGROUND

In the design of refrigeration systems for use aboard Naval vessels, the desire is to make the system as efficient as possible. To achieve this higher efficiency, one must consider the use of a high pressure refrigerant, since this gives a higher energy transfer per unit volume of vapor (i.e., $E_v = h_{fg}/v_g$) [Ref. 1], and results in less of a pressure drop along the vapor path for a given heat load. R-12, which is a high pressure refrigerant, has an energy transfer per unit volume of vapor of 8570 kJ/m^3 [Ref. 2] and, since it is higher pressure, it requires heavier gauge components. R-11, on the other hand, is a low pressure refrigerant with a low energy transfer per unit volume of vapor of 2086 kJ/m^3 and requires lighter gauge material.

Table 1 provides a short summary of some of the available refrigerants and their respective energy transfer per unit volume of vapor, their relative toxicity and their required system pressure for optimum operation. As can be seen from Table 1, R-12 and R-22 possess the highest values of energy transfer per unit volume of vapor, and therefore would provide systems of higher efficiency than the other refrigerants listed since pressure losses in the system would be less. However, since both R-12 and R-22 are

high-pressure refrigerants, their respective systems would be significantly heavier larger than those of the other refrigerants. However, R-114 being a moderate-pressure refrigerant with an energy transfer per unit voulume of vapor of 3800 kJ/m³, it would allow for a relatively lighter component system than those of R-12 and R-22.

TABLE 1 [Ref. 3]
SUMMARY OF REFRIGERANTS

Refrigerant	kJ/m³	Toxicity	Operational System Pressure
R-11	2086	moderate (Group 5)	low
R-12	8570	low (Group 6)	high
R-22	12480	moderate (Group 5)	high
R-113	1128	high (Group 4)	low
R-114	3800	moderate (Group 6)	moderate

Additionally, R-114 belongs to the refrigerant group (Group 6) having the lowest toxicity [ReF. 2], and it has also been proven fairly stable with temperature [Ref. 2]. Therefore, R-114 is a viable alternative to the higher pressure refrigerants.

B. REVIEW OF REFRIGERANT-OIL MIXTURE BOILING BEHAVIOR

The presence of oil in the evaporators of refrigeration systems is a common occurrence. This is due, in part, to the use of lubricants in the hermetically sealed refrigeration compressors. Over a period of time, a considerable amount of oil is introduced into the refrigerant, subsequently changing the physical properties of the refrigerant. Jensen and Jackman [Ref. 3]

reported that the density and the specific heat behave linearly in the refrigerant-oil mixtures, however, the viscosity and the surface tension do not. Henrici and Hesse [Ref. 4] experimentally determined in 1971 that the surface tension of mixtures first decreased for R-114-oil mixtures of up to 2.5 percent oil, and at higher oil concentrations, the surface tension increased. This non-linear behavior of the properties of the mixtures makes it difficult to explain the changes in the heat-transfer coefficient for these mixtures.

The most evident example of the addition of oil to the refrigerant is the presence of foam in the mixture when boiling takes place. With the oil concentration above 1 percent, there is a substantial amount of foam generated from the nucleate boiling surface. This foam is generated because the refrigerant in the refrigerant-oil mixture is more volatile than the oil and therefore can vaporize, creating a gas bubble surrounded by an oil-rich layer [Ref. 5]. Figure 1.1 shows the ideal model of the growth of a bubble in a refrigerant-oil mixture. These generated bubbles are at lower density than that of the surrounding refrigerant-oil mixture. The bubbles ascend to the liquid-vapor interface and collect at the interface and produce a foam layer. As reported by Henrici and Hesse [Ref. 4], the foaming action is most pronounced in refrigerant-oil

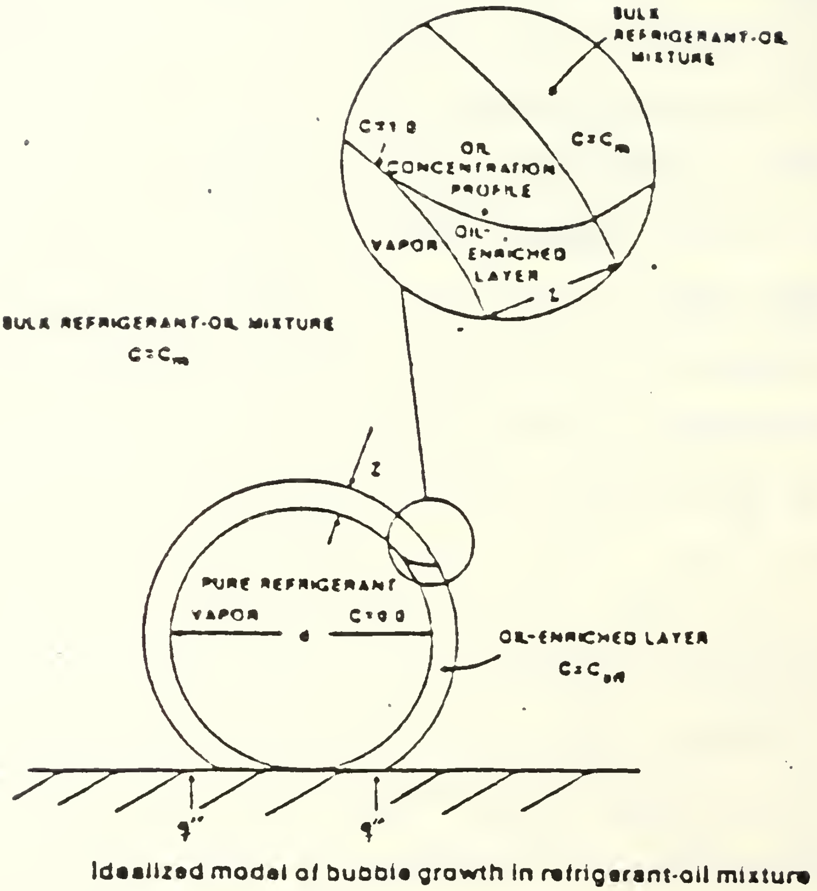


Figure 1.1 Oil Concentration Gradient in a Bubble in Refrigerant-Oil Mixtures [Ref. 5].

mixtures of 1 to 10 percent oil, and provide a the presence of oil results in a subsequent decrease in the heat-transfer performance of the boiling tube.

Numerous researchers have tried to explain the reasons for the decrease in the heat-transfer coefficient in refrigerant-oil mixtures of increasing oil content. Thome [Ref. 6], after an extensive literature search, found that, in 1956, Van Wijk et al. explained the effect as being the result of the evaporation of the more-volatile component leaving an oil-rich layer which has a higher resultant local boiling point. This increased local boiling point requires an increase in the amount of superheat necessary to continue the vaporization and bubble growth. The result is a decrease in the heat-transfer coefficient.

Stephan and Preusser [Ref. 7] determined that the work required to form bubbles in the refrigerant-oil mixtures was greater than in an equivalent amount of pure refrigerant. Therefore, the heat-transfer coefficient was lower for the refrigerant-oil mixture than for the pure refrigerant. Chongrungreong and Sauer [Ref. 8] reported that the rate of heat diffusion, which is governed by the thermal properties of the oil-rich layer, limits the bubble growth and that the effects of surface tension are negligible. Thome [Ref. 6] agreed with the above factors and concluded that the viscosity variations are important

in explaining the decrease in the heat-transfer coefficient for some refrigerant-oil mixtures.

Although researchers have not decided on any one set of factors that determine the reasons for the decrease in the heat-transfer coefficient as oil content increases in refrigerant-oil mixtures, all agreed that the physical and thermal properties are important factors in explaining the heat-transfer behavior of refrigerant-oil mixtures.

C. REVIEW OF BOILING PERFORMANCE FROM SMOOTH TUBES

The U. S. Navy attempts to reduce the size of its shipboard refrigeration systems by the use of alternate refrigerants (such as R-114). At the same time, the Navy desires to increase the performance of these systems by the use of enhanced surfaces. However, as discussed by Wanniarachchi et al. [Ref. 9], only a limited amount of data is available regarding the boiling of refrigerants in the presence of oil.

Stephan [Ref. 10] conducted experiments using a smooth horizontal plate as a boiling surface in R-12 and R-22 refrigerants and reported up to 50 percent reductions in the boiling heat-transfer coefficient with a refrigerant-oil mixture of 9 percent oil (by mass), while 50 percent oil resulted in a 90 percent reduction in the boiling heat-transfer coefficient.

In 1971, Henrici and Hesse [Ref. 4] conducted experiments involving the boiling of R-114 in the presence of oil from a smooth copper tube and reported a maximum decrease of 20 percent decrease in the boiling heat-transfer coefficient with 1 percent oil by mass. In 1981, Stephan and Mitrovic [Ref. 11] reported that for the GEWA-T tube (manufactured by the Wieland Company) in R-114-oil mixtures, the boiling heat-transfer coefficient of the enhanced surface was significantly altered by the presence of the oil. In 1985, Reilly [Ref. 5] reported a drop in the heat-transfer coefficient of 0 to 35 percent (depending on the heat flux) for a R-114-oil mixture of 10 percent oil for a smooth copper tube.

D. REVIEW OF BOILING PERFORMANCE FROM ENHANCED SURFACES

Arai et al. [Ref. 12] tested a 200-ton R-12 centrifugal water chiller. The chiller which used an enhanced-surface tube, commercially known as Thermoexcel-Em made by Hitachi, was 28 percent shorter in length and had an approximate improvement in the overall heat-transfer coefficient of 50 percent. Additional research by Yilmaz and Westwater [Ref. 13], Marto and Lepere [Ref. 14], and Carnavos [Ref. 15] on commercially available enhanced surface tubes, in various refrigerants other than R-114, indicated that a porous-coated surface exhibited the best boiling heat-transfer coefficient in a pure refrigerant.

Comparisons by Reilly [Ref. 5] indicated that in R-114, Union Carbide's "High Flux" tube with a porous-coated surface resulted in an improvement of at least a factor of seven over a smooth copper tube at the same operational parameters. Reilly's findings complemented the research of Yilmaz and Westwater [Ref. 13]. Additionally, Reilly reported that for a porous-coated surface in an R-114-oil mixtures of 1 percent oil, the oil was seen to degrade the nucleate pool-boiling heat-transfer performance by about 20 percent.

1. Surfaces with Reentrant Cavities

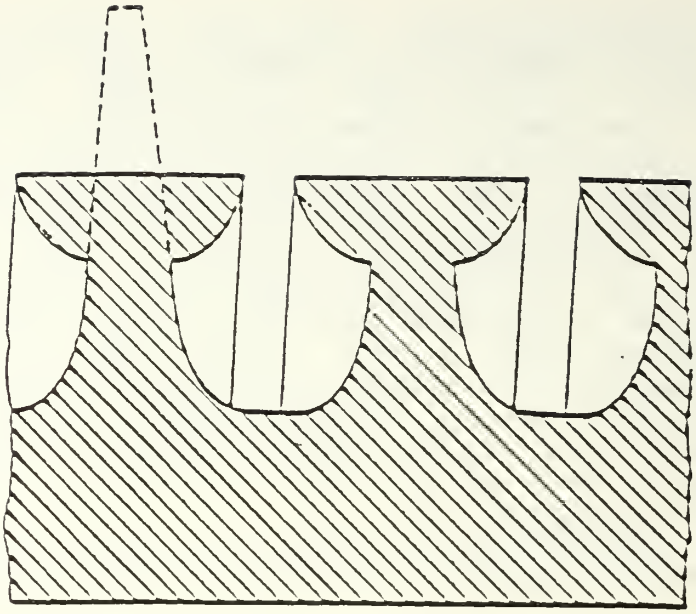
Reentrant cavities have been investigated for a considerable period of time. Griffith and Wallis [Ref. 15] determined that the reentrant cavity geometry is important in the generation of nucleate boiling sites in two ways; (1) the diameter of the reentrant cavity mouth determines the amount of superheat required to initiate boiling, and (2) the cavity shape determines the stability once the boiling has begun. Webb [Ref. 16] stated that the key to the high performance of the reentrant grooved structures can be attributed to three factors: (1) reentrant cavity within a critical size range, (2) interconnected cavities, and (3) nucleation sites of a re-entrant shape. If the cavities are interconnected, adjacent cavities can activate each other. Webb [Ref. 16]

also stated that reentrant cavities provide a stable vapor trap, which can remain active at low values of superheat.

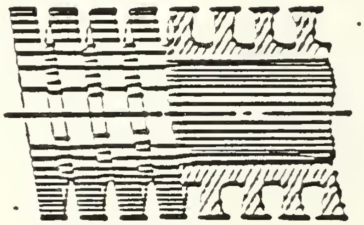
The GEWA-T (1.02 fins/mm) enhanced-surface tube, manufactured by Wieland-Werke AG, is a copper tube with spiral fins of a T-shaped profile. It has a reentrant-type cavity formed by cold working an integral finned tube. The two adjacent T-fins form a spiral cavity with an opening of 0.25-mm (see Figure 1.2).

The Thermoexcel-E and Thermoexcel-HE enhanced-surface tubes are made by the Hitachi Company. Like the GEWA-T tube, the Thermoexcel-E (Figure 1.3) and Thermoexcel-HE (Figure 1.4) tubes are also formed by cold working integral fins; however, these tubes have low fins which have a small space cut out at the fin tips, giving the appearance of a sawtooth. These sawtooth fins are bent parallel to the tube axis, to a horizontal position, forming tunnels with evenly spaced surface pores. This cold working procedure results in a high area density of reentrant nucleation sites. The Thermoexcel-HE tube is a variation of the Thermoexcel-E tube, designed for improved performance in low-heat-flux regions.

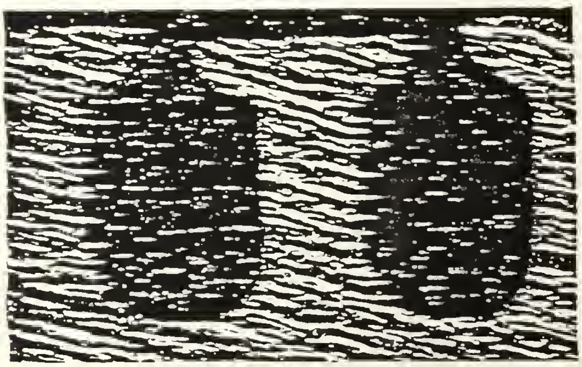
Experimental data showing the effect of oil concentrations on the heat-transfer coefficient of the GEWA-T, the Thermoexcel-E and Thermoexcel-HE tubes in R-114 are lacking. In an effort to gain more understanding of



(a) Schematic of GEWA-T Surface Cross Section



(b) Cutaway of the GEWA-T Surface



(c) Micrograph of the GEWA-T Surface

Figure 1.2 Schematic, Cut-away Cross Section and Micrograph of the GEWA-T Surface.

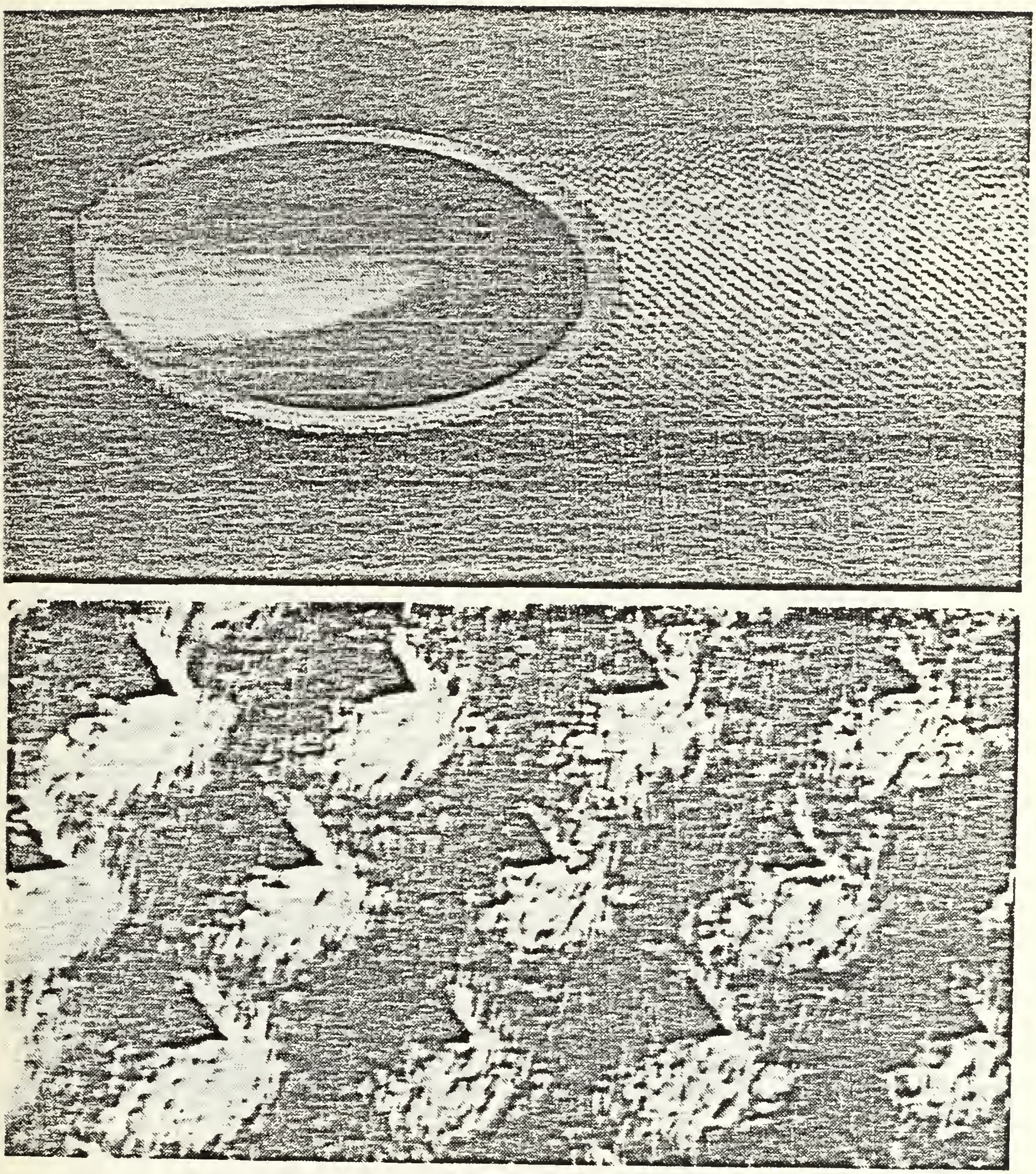


Figure 1.3 Surface Photograph and Enlarged Outer Surface of the Thermoexcel-E Surface.

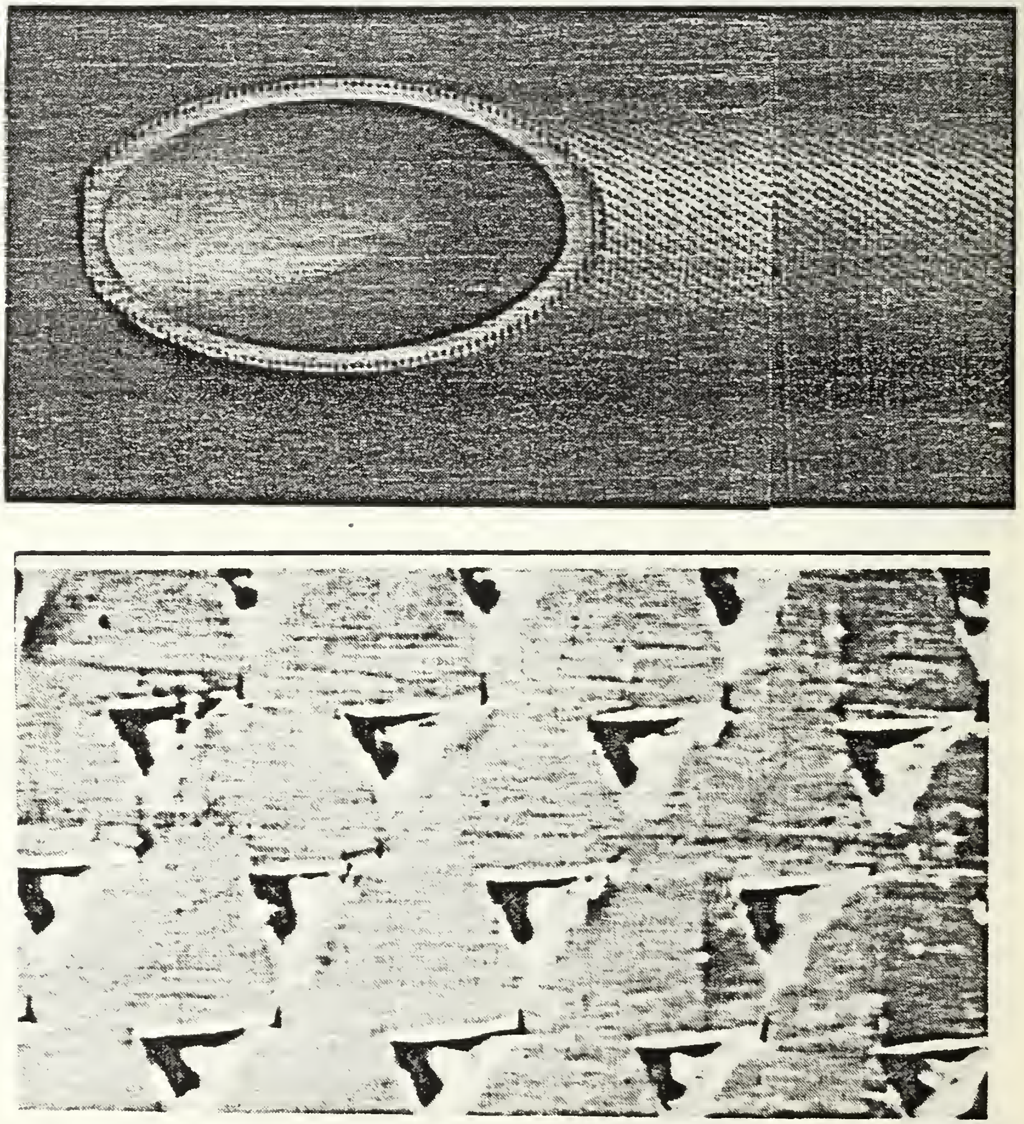


Figure 1.4 Surface Photograph and Enlarged Outer Surface of the Thermoexcel-HE Surface.

the pool-boiling performance of these tubes, the David W. Taylor Naval Ship Research and Development Center sponsored this investigation. The smooth copper tube and the GEWA-T tube were provided by the Wieland Company. The Thermoexcel-E and Thermoexcel-HE tubes were provided by the Hitachi Company.

E. THESIS OBJECTIVE

The objectives of this thesis are:

1. take data on a smooth tube with the use of auxiliary heaters together with a convection shield to enable the collection of more data with a minimum of operator effort,

2. take boiling data on a smooth copper tube in R-114 to provide a baseline for follow-on comparison for enhanced tubes at oil concentrations of 0, 1, 2, 3, 6 and 10 percent (by mass) at a boiling temperature of 2.2 C and a heat-flux range from 500 W/m^2 to 91 kW/m^2.

3. take data on the following tubes for the above-mentioned conditions:

   a. GEWA-T (1.02 fins/mm),

   b. Thermoexcel-E, and

   c. Thermoexcel-HE.

II. DESCRIPTION OF EXPERIMENTAL APPARATUS

A. OVERALL APPARATUS

The equipment used for this study consisted of nine basic components: (a) a Pyrex-glass tee for the pool boiling of the R-114 liquid; (b) a Pyrex-glass tee for the condensing of the R-114 vapor; (c) an R-114 liquid reservoir; (d) a water-ethylene glycol mixture sump; (e) an R-12 refrigeration system with an external proportioning valve; (f) oil reservoir; (g) a vacuum pump; (h) instrumentation and data-acquisition system; and (i) a convection shield. Figure 2.1 shows schematically the arrangement of the various components. Complete details of the design, construction and operation of the apparatus are provided by Karasabun [Ref. 17], Reilly [Ref. 5] and Wanniarchchi et al. [Ref. 1]. The original design of Karasabun was modified by the inclusion of the convection shield in the pool-boiling section as shown in Figures 2.2 and 2.3.

The operation of the apparatus consisted of the boiling of R-114 liquid in the lower glass tee (1), and condensing of the R-114 vapor in the upper glass tee (2). The resultant condensate was fed to the distribution tube within the boiling section by gravity. A water-ethylene glycol mixture from a 30-gallon

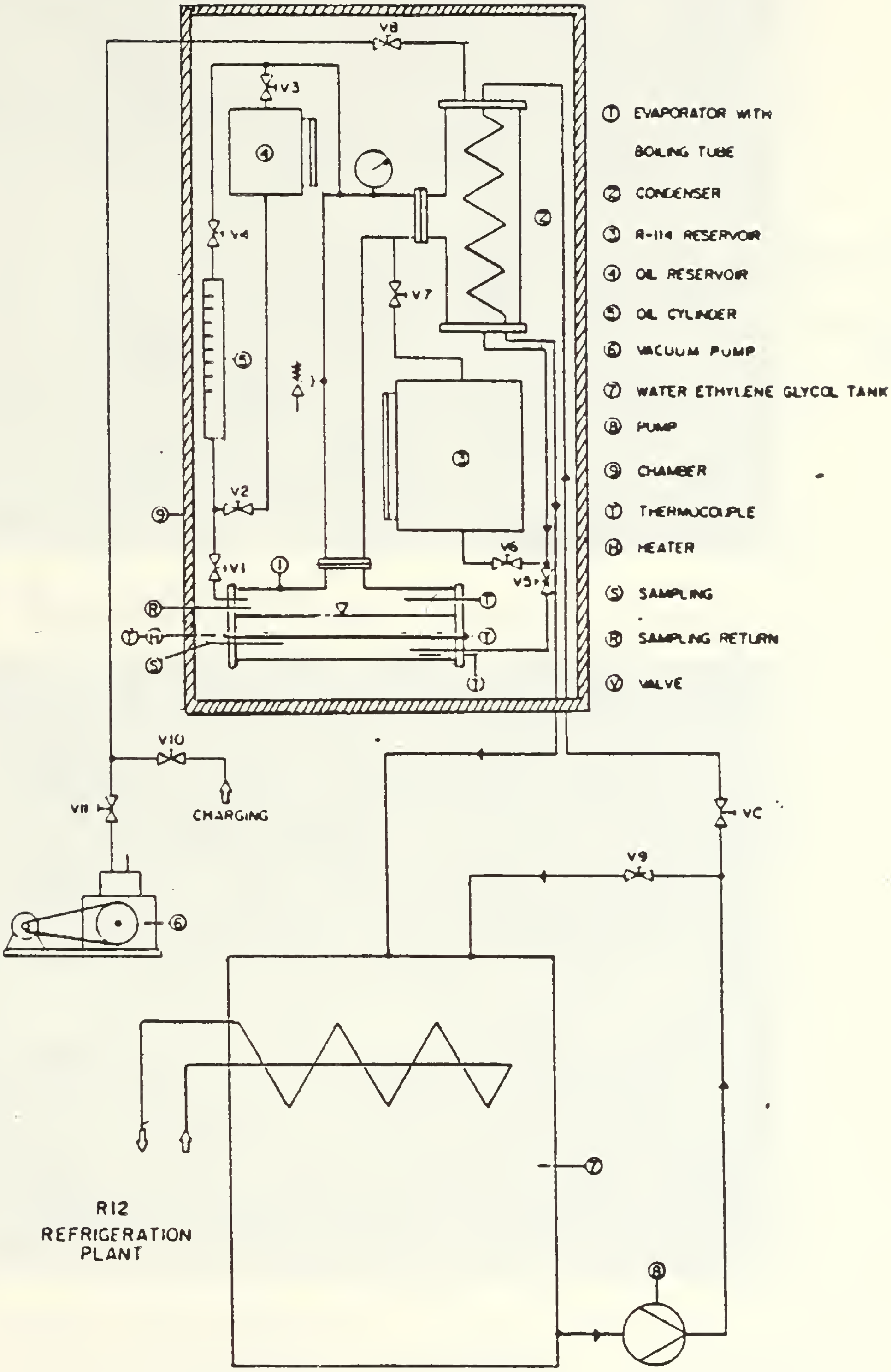


Figure 2.1 Schematic of Experimental Apparatus.

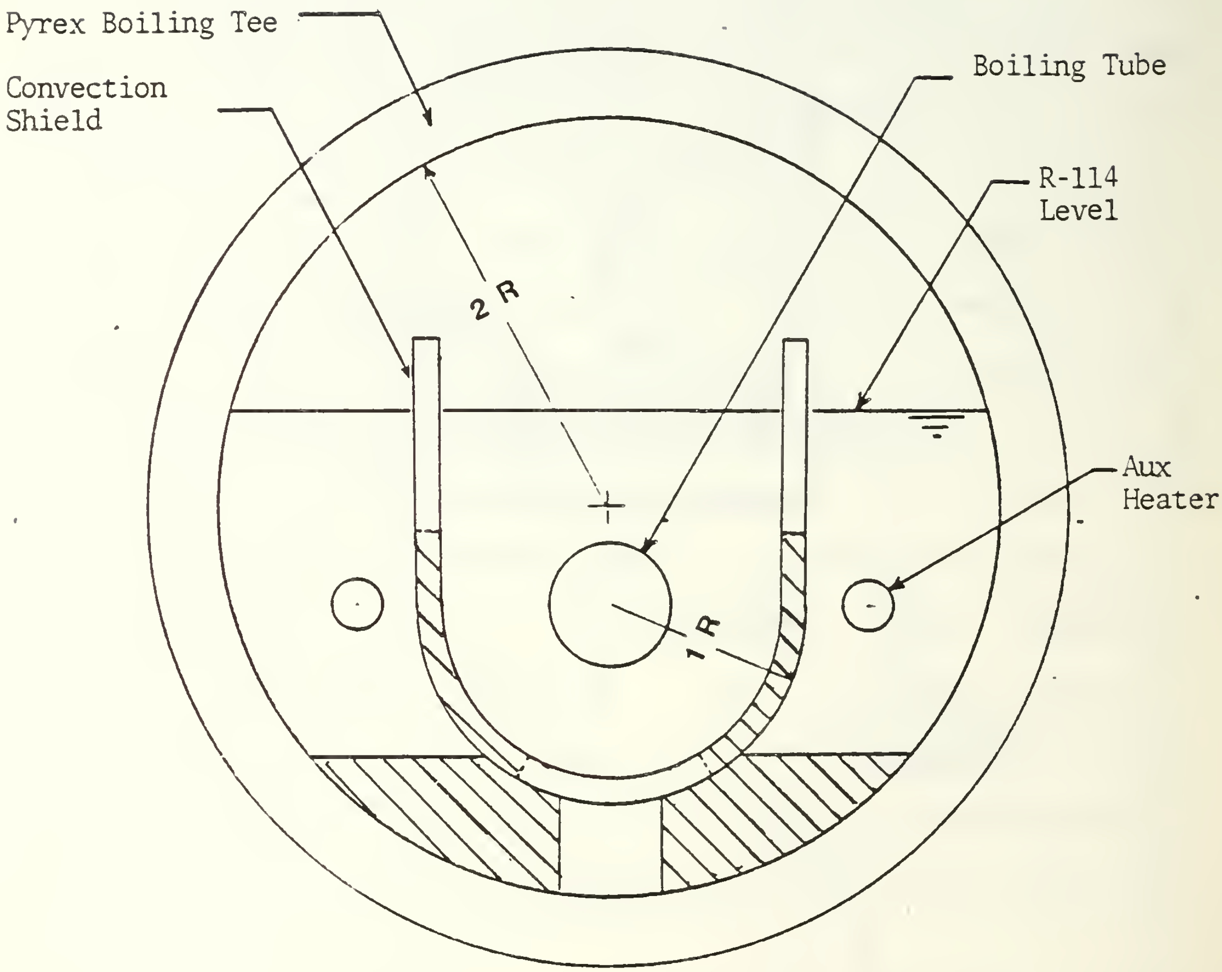
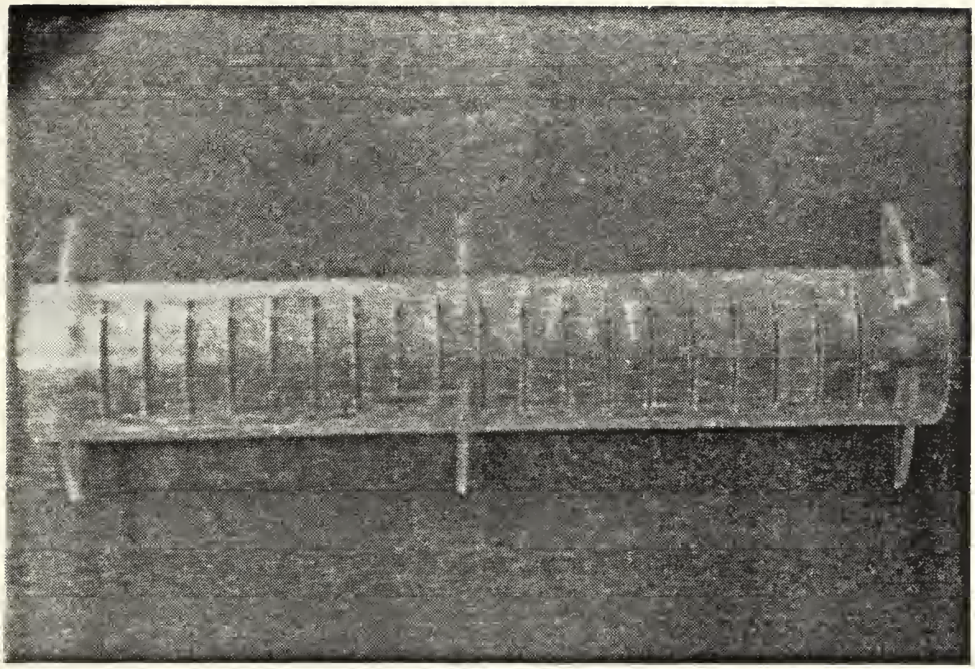
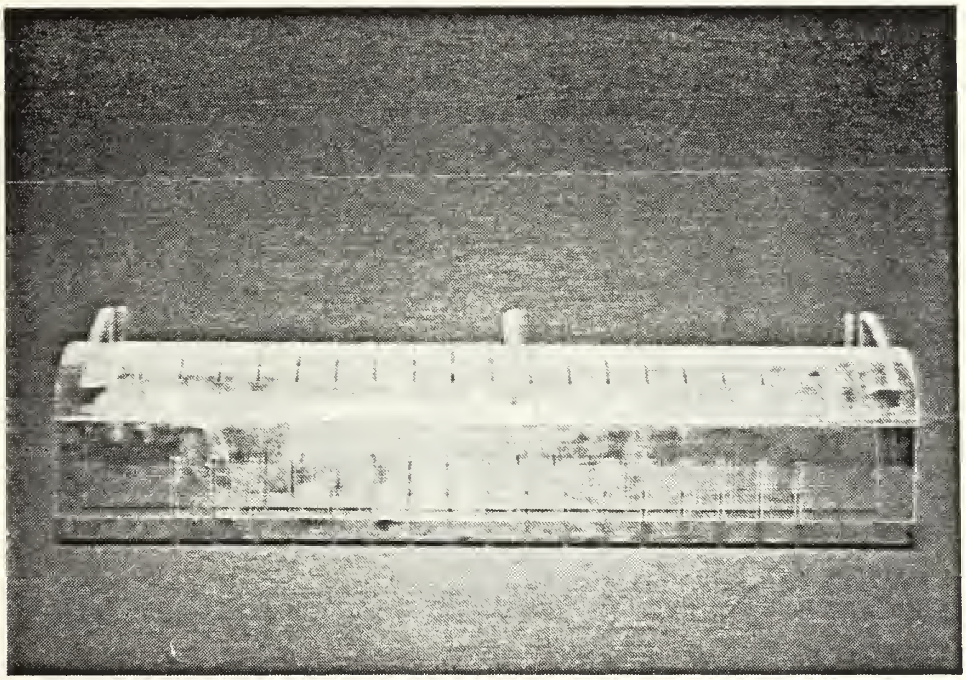


Figure 2.2 Schematic of Convection Shield in Pyrex Boiling Tee.



(a) Bottom View



(b) Side View

Figure 2.3 Photograph of Convection Shield.

sump was used to cool the copper condensing coil, thereby condensing the R-114 vapor. This water-ethylene glycol mixture sump was maintained between -18 and -14 C by a one-half ton R-12 air-conditioning system. The mixture was pumped through the condensing coil and controlled manually with valve VC.

Valve VC controls the amount of the water-ethylene glycol mixture to the condensing coil, thereby controlling the pressure within the test loop. For example, the opening of valve VC allows more of the water-ethylene glycol mixture to pass through the condensing coil, resulting in additional condensing of the R-114, and subsequently lowering the temperature and pressure within the entire system.

As the subcooled R-114 condensate enters the boiling section of the apparatus through the distribution tube, it strikes the convection shield. This shield provides increased mixing of the subcooled R-114 condensate with the remaining R-114 (or R-114/oil mixture) in the lower portion of the boiling section. The shield deflects the incoming condensate away from the boiling surface and allows for further mixing of the condensate and the existing R-114 liquid by means of the auxiliary cartridge heaters. This deflection of the incoming condensate allowed for a more even temperature distribution of the liquid R-114 and therefore decreased the previously reported temperature

gradients within the liquid region. This additional mixing of the liquid R-114, coupled with the ability to use auxiliary cartridge heaters in the liquid and allowed for the timely achievement of steady-state conditions without the previously observed thermal gradients in the liquid region of the tests done without the aid of the convection shield. It was also observed throughout the operation of the apparatus that the data obtained using the convection shield had a higher degree of repeatability than the data obtained without the shield.

B. BOILING-TUBE CONSTRUCTION

The tubes tested during the course of this study were the smooth copper tube, the GEWA-T (1.02 fins/mm), the Thermoexcel-E and the Thermoexcel-HE tubes. All of these tubes had an active test section (i.e., heated) of length of 203.2-mm (8 in), with an outside diameter of 15.9 mm (5/8 in) and an inside diameter of 12.7 mm (1/2 in). The remaining 114.3-mm section on either side of the heated test section was smooth and unheated and did not nucleate under any heat flux or any oil concentration condition. Figure 1.2 shows the schematic of the GEWA-T finned surface. Karasabun [Ref. 17] described the analysis used in the data-reduction program, allowing for the two end surfaces to be treated as extended fins from the center section and subsequently accounting for the heat losses.

The center section of each tube tested was heated by a 1000-W 240-V stainless steel cartridge heater inserted in the center section of each tube. The cartridge heater was inserted in the boiling tube and surrounded by a copper sleeve with eight 1.3 mm by 1.3 mm thermocouple channels. Figure 2.4 shows the layout of the installed tube in the boiling section. Figure 2.5 shows the details of the thermocouple layout. The thermocouple hot junctions were inserted into the copper sleeve and the copper sleeve was then tinned; and heat was maintained to keep the solder in a molten state as the sleeve was inserted and positioned in the center section of the boiling tube. Upon completion of the thermocouple installation, calibration of the thermocouples was achieved. Reilly [Ref. 5] determined in the course of his investigation that since the data-reduction program utilized the differences between the thermocouples in all computations, such as wall temperatures minus saturation temperatures, the corrections provided by the thermocouple calibration were basically unnecessary since the calibration procedures were only necessary for items dependent on absolute temperature. Appendix A summarizes the procedure used by Karasabun [Ref. 17] and Reilly [Ref. 5] to calibrate the thermocouples.

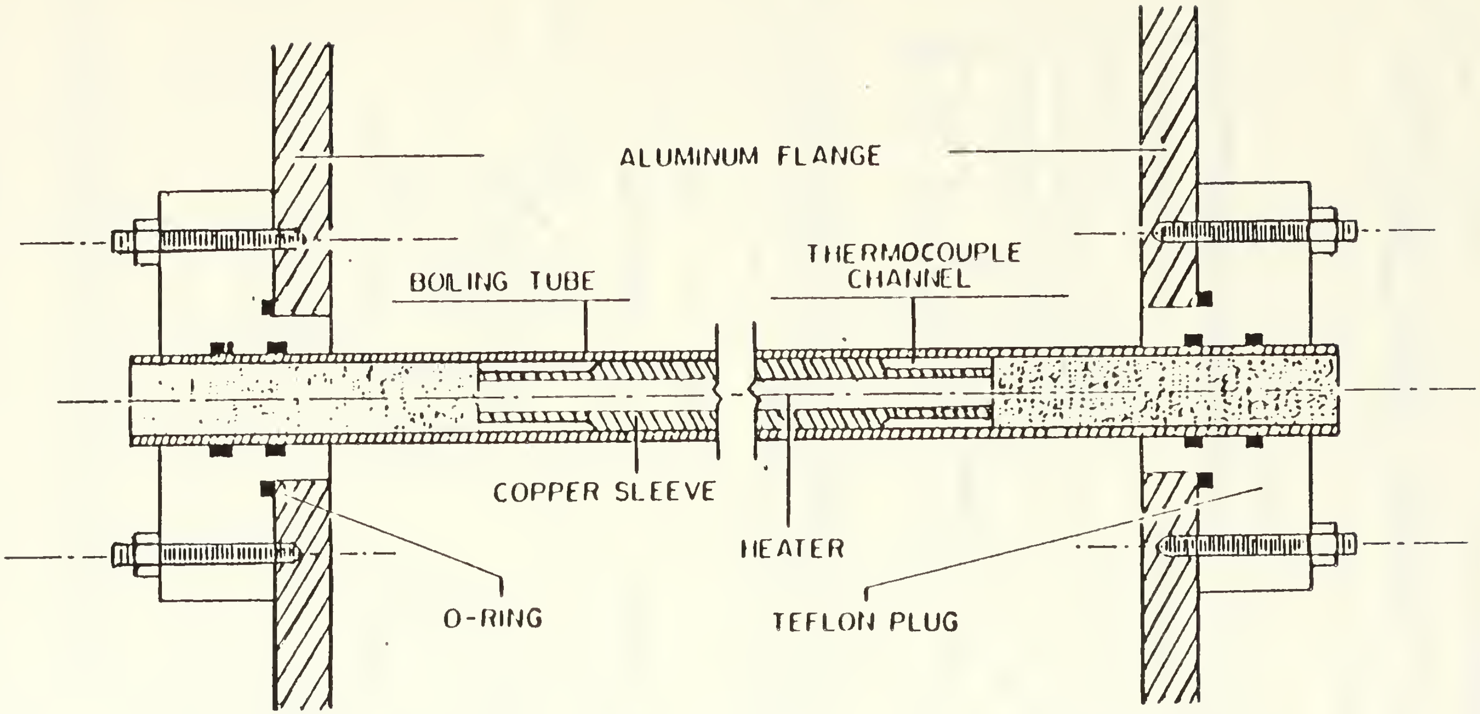
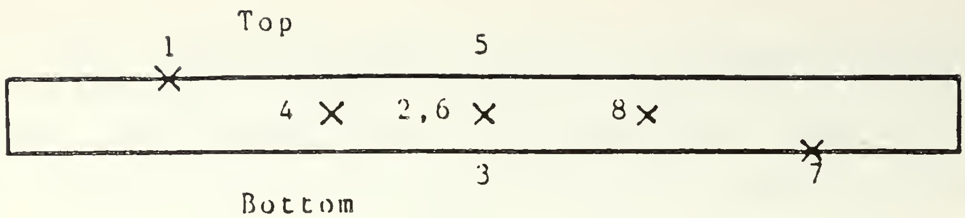
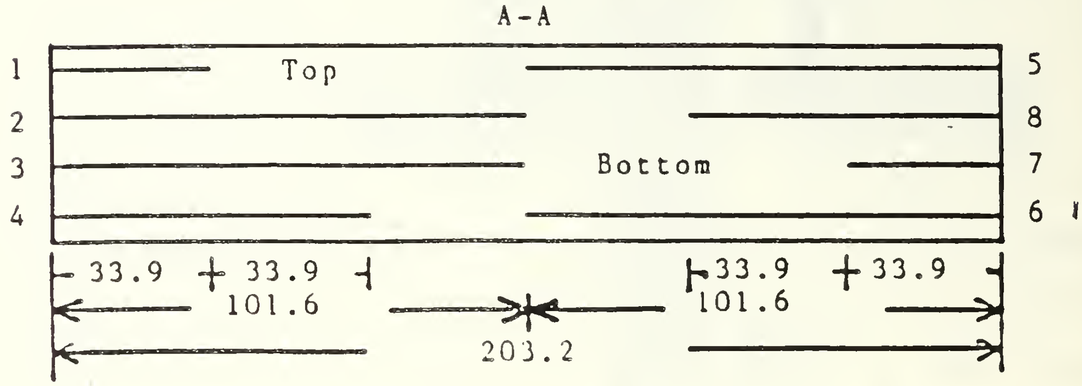


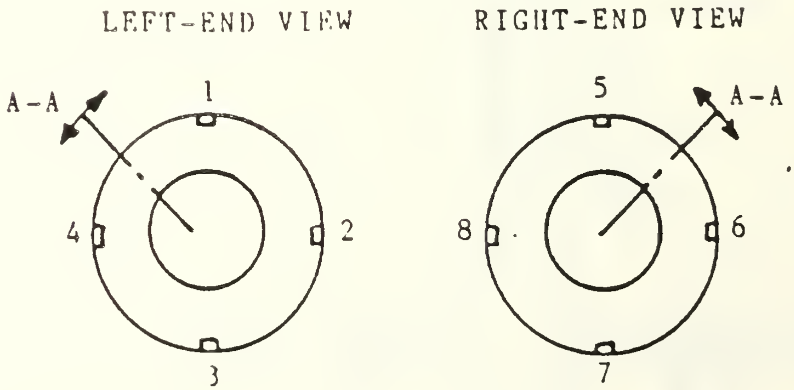
Figure 2.4 Sectional View of Boiling Tube



(a) View of the boiling tube thermocouple locations as seen from the front of the experimental apparatus.



(b) Thermocouple sleeve unwrapped (at section A-A) to show the relative locations of the thermocouple channels (all dimensions in millimeters).



(c) End views of the boiling tube.

Figure 2.5 Boiling Tube Thermocouples Channels.

C. CONVECTION SHIELD

Initial tests on the smooth copper tube revealed an axial thermal gradient in the liquid over the length of the boiling tube. This thermal gradient increased with increasing oil concentration and with increasing heat flux, with the thermal gradient ranging from 0.5 K to 1.5 K over the length of the boiling section. This thermal gradient resulted in questionable data since steady-state conditions could not be maintained over the course of the individual data runs.

During the early stages of this investigation, it was found that the steady-state conditions were fairly difficult to achieve. This was especially true after making a step change in the heat flux. For example, if the heat flux was increased, the cooling flow rate to the condenser must be increased to maintain the system pressure. Since the system showed about a 30-second time lag between the change of the valve position and the subsequent system response, the pressure was often seen to undergo cyclic variations. With considerable experience of the operator, it was possible to achieve steady-state conditions within 5 to 10 minutes, as demonstrated by Reilly [Ref. 5].

In order to minimize the efforts necessary by the operator, two 600-W auxiliary cartridge heaters were installed within the boiling tee. With this arrangement, steady-state conditions could be maintained very easily by

maintaining the total heat load in the boiling tee at a constant value. For example, if the heat duty for the boiling tube was increased, the heat duty on the auxiliary heaters must be decreased by the same magnitude. In this manner, steady-state conditions could be maintained with minimum attention. However, this arrangement required that the heat duty on the auxiliary heaters be a maximum when the heat duty on the boiling tube is at a minimum. As determined by the early data runs (see Figure 2.6), the convective effects created by the bubbles of the auxiliary heaters created an artificially enhanced heat-transfer coefficient at low heat-flux settings.

In order to alleviate the problem discussed above, while maintaining the advantages offered by the auxiliary heaters, the present investigator considered the use of a convection shield. As shown in Figure 2.2, this shield was positioned around the test tube, thus isolating it from the convective bubble effects created by the auxiliary heaters.

The convection shield also provided increased mixing of the refrigerant and condensate without interfering with the boiling phenomenon of the boiling tube or the circulation of the oil-refrigerant mixture in the boiling section by both the boiling tube and the auxiliary heaters.

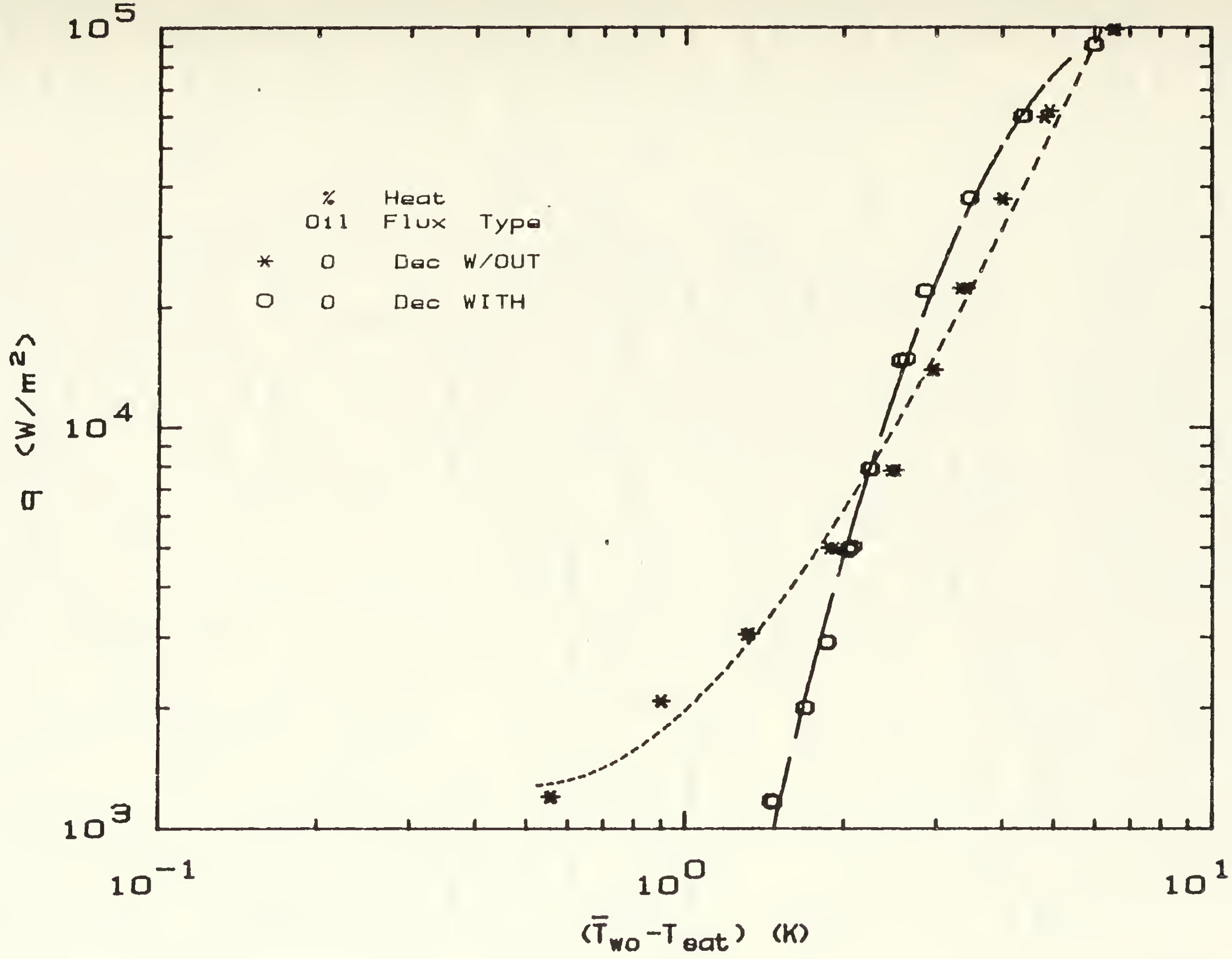


Figure 2.6 Convective effects of Auxiliary Heaters with and without Convective Shield

D. DATA ACQUISITION AND REDUCTION

The data-acquisition system used for this research was a Hewlett-Packard 9826A computer and a Hewlett-Packard 3497A Automatic Data Acquisition Unit. The HP-9826A computer was used to control the HP-3497A, to provide hard-copy storage capacity and to analyze the data obtained during this investigation.

The data-acquisition system provided the means by which the researcher was able to review system performance and stability prior to the taking of any data. System parameters were monitored on the video screen following the scanning of all of the channels by the HP-3497A. Following the automatic scanning of all of the channels, the computer would display the desired saturation temperature (2.2 °C), the observed saturation temperature, the liquid temperature at both ends of the boiling section and their average, the vapor temperature, and the temperature of the water-ethylene glycol mixture sump (-15 to -18 °C). Once the steady-state conditions were met for the required saturation temperature within the prescribed variance (±0.1 K) of the desired saturation temperature, the data-acquisition system was initiated for the individual data run. Since there was a time lag in the request for the taking of data and the actual printing of the data due to the sampling of each channel twenty times before recording the data, the data-acquisition system would print the data,

allowing the researcher to review the results prior to storing the data. If, during the sampling of the data, a transient trend was observed due to the cycling of the R-12 refrigerant system or the temperature difference between the thermocouples measuring the liquid R-114 was not within the specified temperature range, the researcher had the capability to reject the affected data set. This capability allowed the researcher to apply a cursory analysis of each data point and ascertain if the temperatures measured during that individual data set were within the prescribed limits of variance.

The information scanned on each channel of the HP-3497A were thermal emf's provided by copper-constantan (type-T) thermocouples made of 0.25-mm-diameter (30 gauge) wire. Two additional measurements were provided to the HP-3497A by the power-sensing device, as described by Karasabun [Ref. 17], which converted the AC voltage dialed into the variac of the main boiling tube heater into a DC signal, allowing the HP-3497A to accurately scan the converted value and then allow the HP-9826A to automatically apply this value to the analysis calculation.

Upon the initiation of the command to take data, the data-acquisition system would sample each channel and then compute, according to the step-wise procedure outlined by Karasabun [Ref. 17] and print the results. Appendix B contains a summary of the data-acquisition program and a

listing of the data-reduction program utilized during the course of this research. Appendix C contains a representative sample of the data printout received for each data run.

III. EXPERIMENTAL PROCEDURES

A. INSTALLATION OF TUBE IN BOILING APPARATUS

The external surfaces of each of the boiling tubes were cleaned with Nitol (2 percent nitric acid and 98 percent ethyl alcohol) solution and then rinsed with acetone to ensure tube cleanliness. This treatment was also effective in the removal of oil and grease residues from the tube surfaces.

After air drying, the individual tube to be tested was installed in the boiling section of the apparatus. The system was sealed and then evacuated to approximately 29 inHg by means of a portable mechanical vacuum pump (6), shown in Figure 2.1. The apparatus remained under the evacuated condition for a period of about one hour to check if there were any major leaks. System pressure was measured by means of a Marsh pressure gauge (30 inHg to 150 psi range with ± 2.5 inHg and ± 0.5 psi accuracy, respectively). If there was not a noticeable drop in the vacuum reading as observed on the pressure gauge, the system was charged with R-114 vapor, which was condensed by the water-ethylene glycol mixture and then the absolute pressure was raised to approximately 0.186 MPa (27 psi). Upon reaching this pressure, an Automatic Halogen Leak

Detector, TIF 5000, with a sensitivity of 3 ppm concentration, was used to check for system leaks.

Upon successful completion of the leak-detection tests and taking the necessary steps to fix any leaks found, the R-114 liquid level was adjusted to be 20 mm above the top of the boiling tube surface. Liquid-level adjustments were made by either boiling off the excess refrigerant to the R-114 reservoir (3), or drawing the required amount of refrigerant liquid into the system from the R-114 reservoir. The required liquid level for boiling was maintained constant for all tubes tested by means of a permanent scribe mark on the inside of the oil intake endbell of the boiling section. At this initial refrigerant level, the system was now ready for boiling tests in pure refrigerant.

B. GENERAL SYSTEM OPERATION

Table 2 provides a summary of all of the 83 data runs made during this investigation. Each data run is annotated to indicate the conditions involved in the respective run. The data runs were numbered sequentially with an indicator code for each tube preceding the number of the data run. Since this research is a follow up of previous research, the initial data run was indicated as number 168. All data runs were undertaken at a saturation temperature of 2.2°C.

A listing of the boiling tube indicator codes for Table 2 is as follows:

WH -- Wieland Hard Copper Smooth Tube
GTB -- Wieland Gewa-T (1.02 fins per mm)
TXE -- Hitachi Thermoexcel-E
THE -- Hitachi Thermoexcel-HE.

Initially, all data runs were taken over a range of nine different heat-flux settings, ranging from 2 kW/m^2 to 91 kW/m^2. Additional heat fluxes of 0.5, 0.8, 1.2 kW/m^2 were later included for all tubes with enhanced surfaces to study the onset of nucleate boiling in the oil-refrigerant mixtures and to study the effects of hysteresis on these tubes. The initiation of all data runs was carried out in the same manner to ensure consistency in the obtained data. Each run was started by an initial system "warm-up" period allowing the R-12 refrigeration system to obtain a minimum coolant starting temperature of about -15°C. This was accomplished by lighting off of the R-12 system in conjunction with the effluent recirculation/cooling pump (8) and slight opening of the control valve VC. This procedure allowed the system to gradually decrease system temperature and pressure, while minimizing the adverse effects of shocking the boiling tube. The system was operated in this condition until a stable condition was established with the saturation temperature of 2.2°C. This operation was most critical when the testing sequence involved increasing heat-flux conditions since

TABLE 2
Summary of Data Runs

Run No.	% Oil	Heat Flux	No. of Data Points	Auxiliary Heater	Convection Shield
WH168	0	DEC	20	off	without
WH169	0	INC	22	off	without
WH170	1	DEC	20	off	without
WH171	1	INC	22	off	without
WH172	2	DEC	20	off	without
WH173	2	INC	20	off	without
WH174	3	DEC	20	off	without
WH175	3	INC	22	off	without
WH176	3	DEC	20	off	without
WH177	6	DEC	20	off	without
WH178	6	INC	21	off	without
WH179	10	DEC	18	off	without
WH180	10	INC	13	off	without
WH181	10	INC	12	off	without
GTB182	0	DEC	24	on	with
GTB183	0	INC	23	on	with
GTB184	0	DEC	22	on	with
GTB185	1	DEC	20	on	with
GTB186	1	INC	22	on	with
GTB187	2	DEC	34	on	with
GTB188	2	INC	18	on	with
GTB189	3	INC	22	on	with
GTB190	3	DEC	20	on	with
GTB191	6	DEC	27	on	with
GTB192	6	INC	20	on	with
GTB193	10	INC	20	on	with
GTB194	10	DEC	21	on	with
WH195	0	INC	22	on	with
WH196	0	DEC	20	on	with
WH197	0	DEC	17	on	with
WH198	0	INC	22	on	with
WH199	1	INC	20	on	with
WH200	1	DEC	20	on	with
WH201	2	INC	20	on	with
WH202	2	DEC	20	on	with
WH203	3	INC	20	on	with
WH204	3	INC	20	on	with
WH205	3	DEC	20	on	with
WH206	3	INC	21	on	with
WH207	6	DEC	20	on	with
WH208	6	INC	20	on	with
WH209	10	INC	20	on	with

TABLE 2
Summary of Data Runs (cont'd)

Run No.	% Oil	Heat Flux	No. of Data Points	Auxiliary Heater	Convection Shield
WH210	10	DEC	21	on	with
TXE210	0	DEC	18	on	with
TXE211	0	DEC	12	on	with
TXE212	0	DEC	12	on	with
TXE213	0	DEC	14	on	with
TXE214	0	DEC	12	on	with
TXE215	0	INC	27	on	with
TXE216	0	DEC	14	on	with
TXE217	1	INC	27	on	with
TXE218	1	DEC	14	on	with
TXE219	2	DEC	16	on	with
TXE220	2	DEC	16	on	with
TXE221	2	INC	25	on	with
TXE222	3	DEC	15	on	with
TXE223	3	INC	22	on	with
TXE224	3	INC	24	on	with
TXE225	6	INC	30	on	with
TXE226	6	DEC	16	on	with
TXE227	6	INC	25	on	with
TXE228	10	INC	24	on	with
TXE229	10	DEC	25	on	with
TXE230	10	INC	20	on	with
THE231	0	INC	20	on	with
THE232	0	DEC	12	on	with
THE233	1	DEC	14	on	with
THE234	1	INC	24	on	with
THE235	1	INC	27	on	with
THE236	2	DEC	14	on	with
THE237	2	INC	12	on	with
THE238	2	INC	8	on	with
THE240	3	DEC	14	on	with
THE241	3	INC	18	on	with
THE242	3	INC	8	on	with
THE243	3	INC	5	on	with
THE244	3	INC	5	on	with
THE245	6	DEC	14	on	with
THE246	6	INC	24	on	with
THE247	6	INC	18	on	with
THE248	10	DEC	14	on	with
THE249	10	INC	24	on	with

failure to strictly adhere to this would result in premature nucleate boiling and the subsequent purging of the data. This initial warm-up period required a minimum of one hour to ensure adequate system performance.

Upon reaching stable conditions, the initial heat flux for the boiling tube was set by means of the resistor variac. Also, the heat flux for the auxiliary cartridge heaters was set by a second variac. The heat flux of the auxiliary cartridge heaters was limited to settings that allowed the heating of the liquid R-114 without creating excess turbulence on the boiling tube. As discussed earlier, the boiling tube was shielded from the effects of the auxiliary heater by means of the convection shield. As the oil concentration of the refrigerant-oil mixture increased, the heat-flux setting for the auxiliary heater was additionally limited to lower heat fluxes. This precluded the generated oil foam from carrying over the sides of the convection shield and interfering with the operation of the boiling tube.

After setting of the desired heat flux for the data run, the system was monitored for the vapor temperature, sump temperature and the liquid refrigerant temperature (two readings; left side and right side of the boiling tube). Control valve VC was adjusted to allow the system to reach steady-state conditions. Additionally, the liquid refrigerant temperatures were compared to ensure minimum

variance. After fulfilling the requirements of the steady-state conditions, the data-acquisition system was initiated to take data.

The data-acquisition system would scan each assigned channel, compute the heat-transfer coefficient and print the results for operator viewing. If the data were within the prescribed limits, they were stored on a floppy disk for permanent records. A representative sample of a data printout is contained in Appendix B.

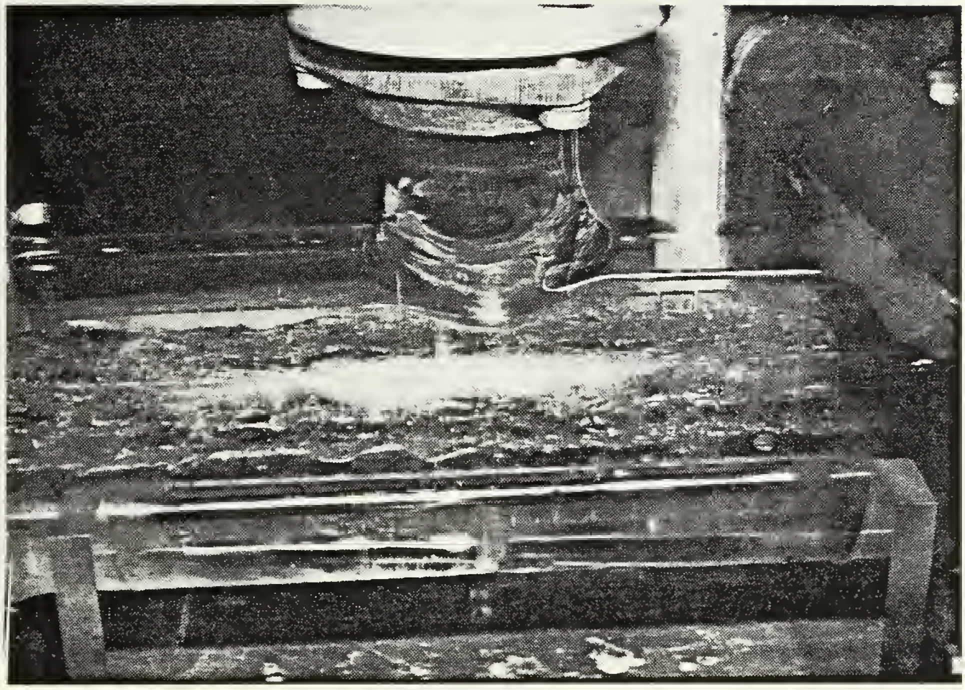
After each run was completed, oil was added to the boiling section by means of a graduated cylinder through valve V1. Table 3 contains the listing of the required volume of oil added to obtain the proper mass percent of oil for each series of data runs. Mixing of the oil and refrigerant liquid was accomplished by means of the auxiliary heater, to ensure a homogeneous mixture. Foaming of the oil-refrigerant mixtures was observed over the entire heat-flux range of each data run, although carryover of the foam over the convection shield was limited to the highest heat flux. As the oil concentration increased, carryover increased, but was limited to the vertical section of the apparatus. Carryover oil was not observed in the condenser section of the apparatus. Figures 3.1 to 3.3 demonstrate the foaming action of

the oil-refrigerant mixtures at a heat flux of 37 kW/m² for oil concentrations of 0, 6 and 10 percent.

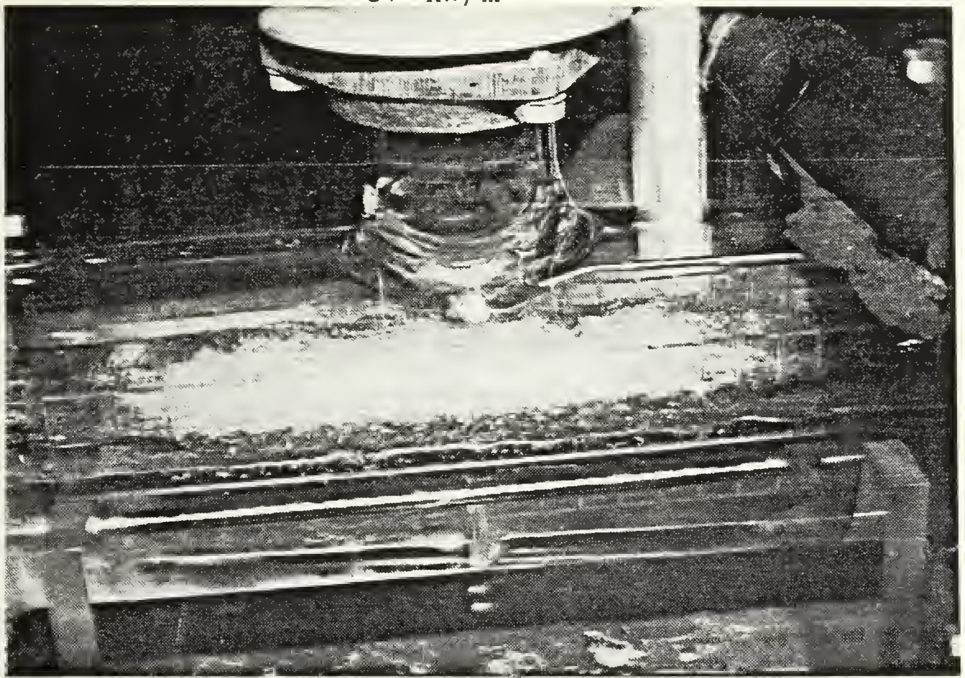
Data runs were made for each boiling tube tested with pure R-114 and followed by runs of oil-refrigerant mixtures of increasing oil content. Oil-refrigerant mixtures of 1, 2, 3, 6 and 10 percent oil by mass were used for all tubes.

TABLE 3
OIL CONCENTRATIONS VALUES

Percent Oil	Total Volume (cc) of Oil	Step Change (cc) in Volume of Oil
0	---	---
1	26.8	26.8
2	54.2	27.4
3	82.2	28.0
6	169.6	87.4
10	295.2	125.6

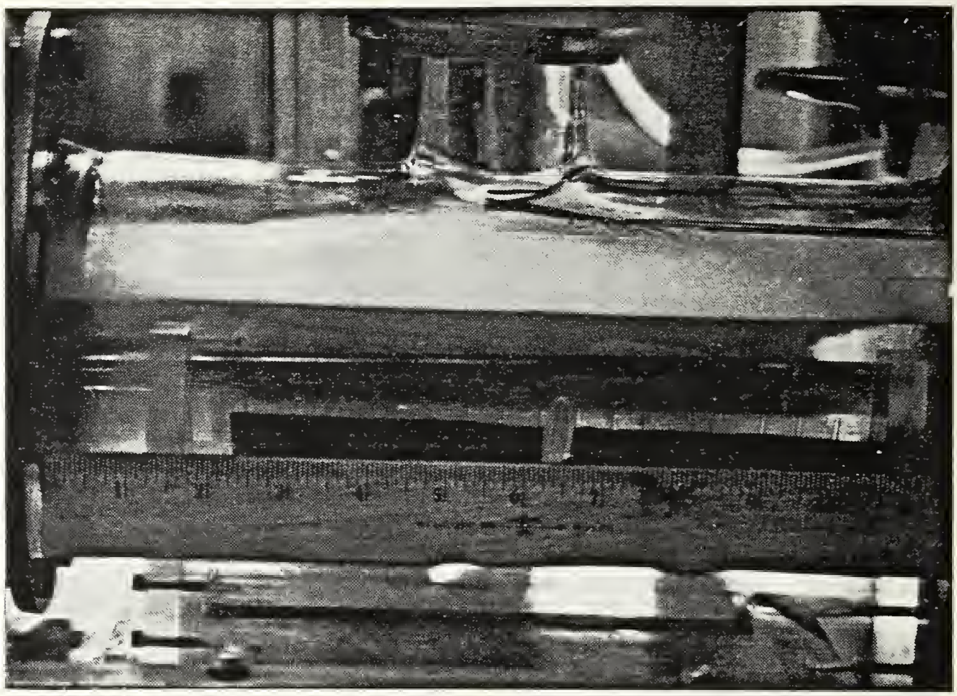


37 kW/m^2

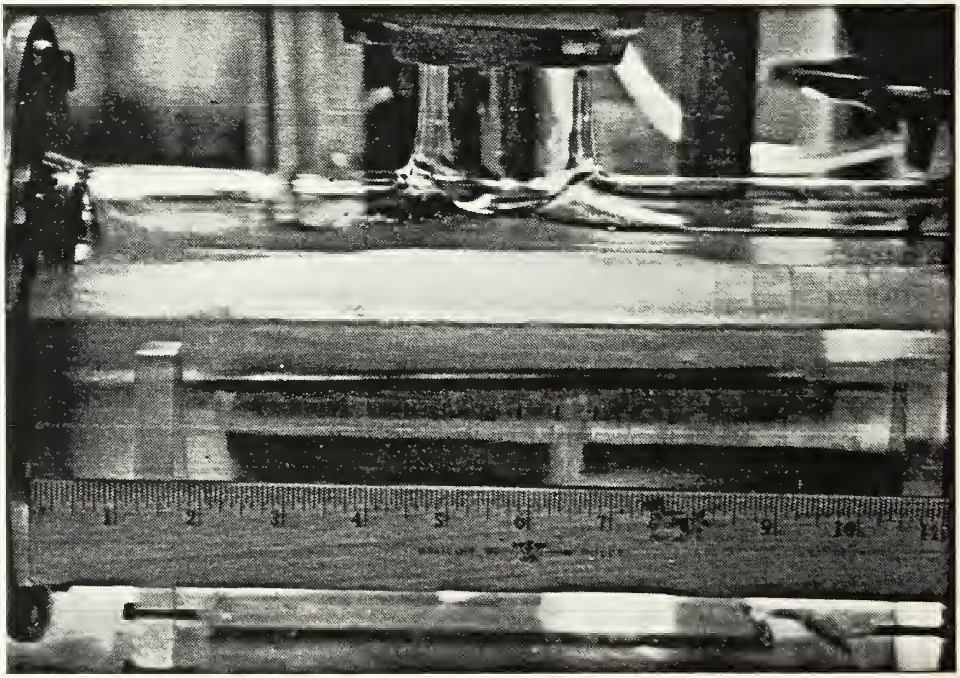


91 kW/m^2

Figure 3.1 Foaming Action for Pure R-114

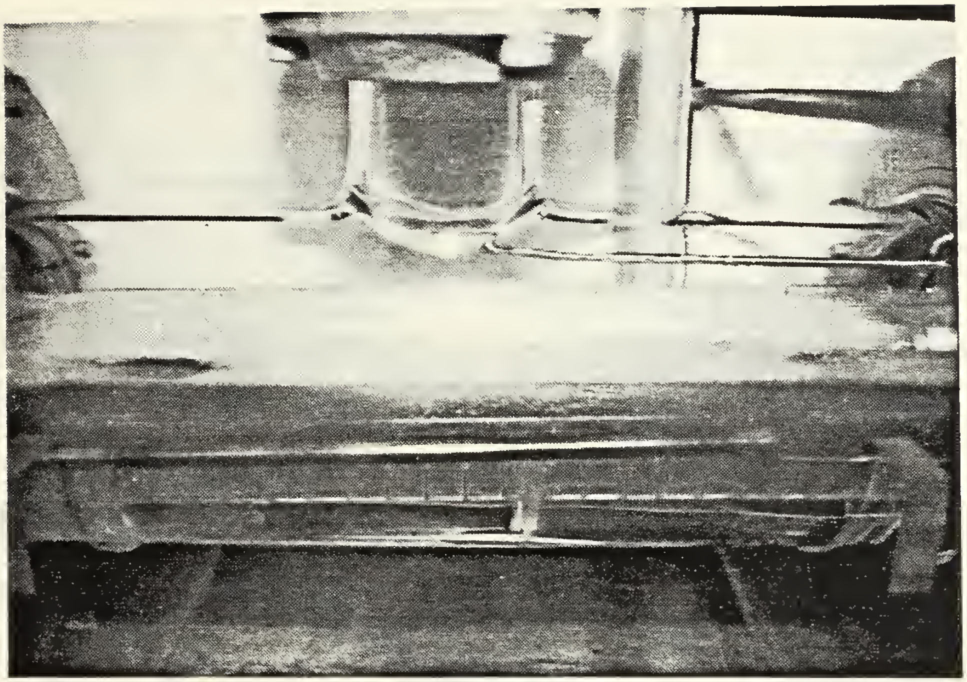


37 kW/m^2

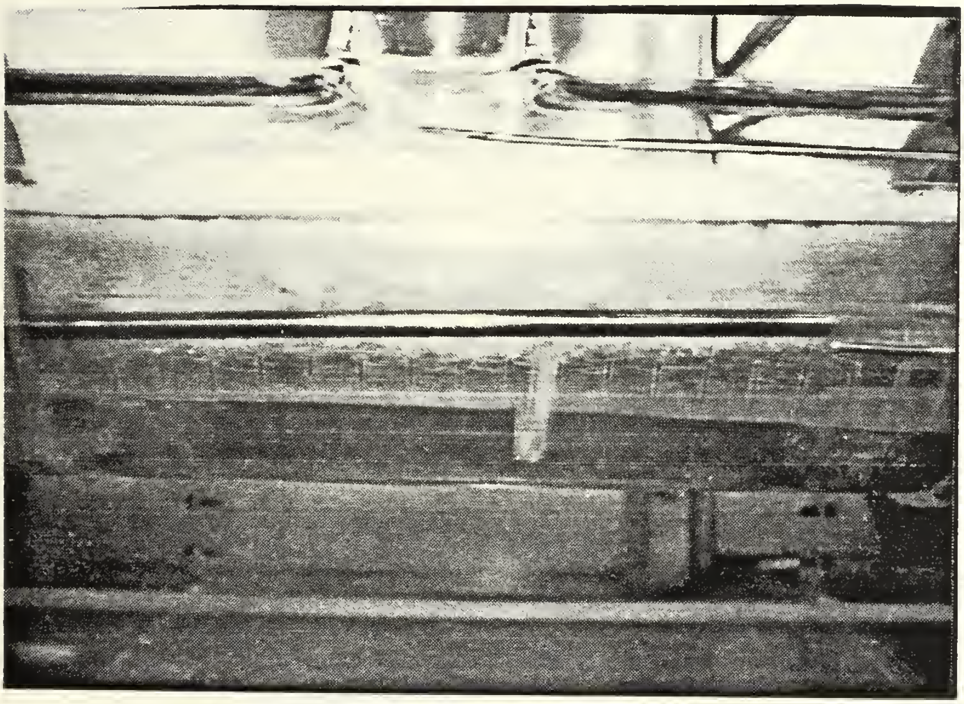


91 kW/m^2

Figure 3.2 Foaming Action for R-114 with 6 Percent Oil



37 kW/m^2



91 kW/m^2

Figure 3.3 Foaming Action for R-114 with 10 Percent Oil

IV. RESULTS AND DISCUSSION

A. EFFECT OF CONVECTION SHIELD

Two sets of data runs were taken on the smooth copper tube; one set without the convection shield to validate the performance in comparison with the data obtained by Reilly (at a saturation temperature of $-2.2^{\circ}C$) [Ref. 5]; and a second data run using the convection shield and the auxiliary cartridge heaters. These data runs allowed for an accurate comparison of the data taken over a period of time and provided justification for the use of the convection shield. As can be seen from Figures 4.1, 4.2 and 4.3, for 0, 3 and 10 percent oil concentration, respectively, the present data with and without the shield in place are essentially the same. However, as discussed in section II.C, the use of the shield provided consistent steady-state conditions over the entire range of heat fluxes and oil concentrations, thereby minimizing the efforts required by the operator.

Figure 4.1, which contains the data run for pure refrigerant for the smooth copper tube at a saturation temperature of $2.2^{\circ}C$, with and without the shield, demonstrates the repeatability of the data. Also plotted on this figure are Reilly's smooth-tube data for pure refrigerant at a saturation temperature of

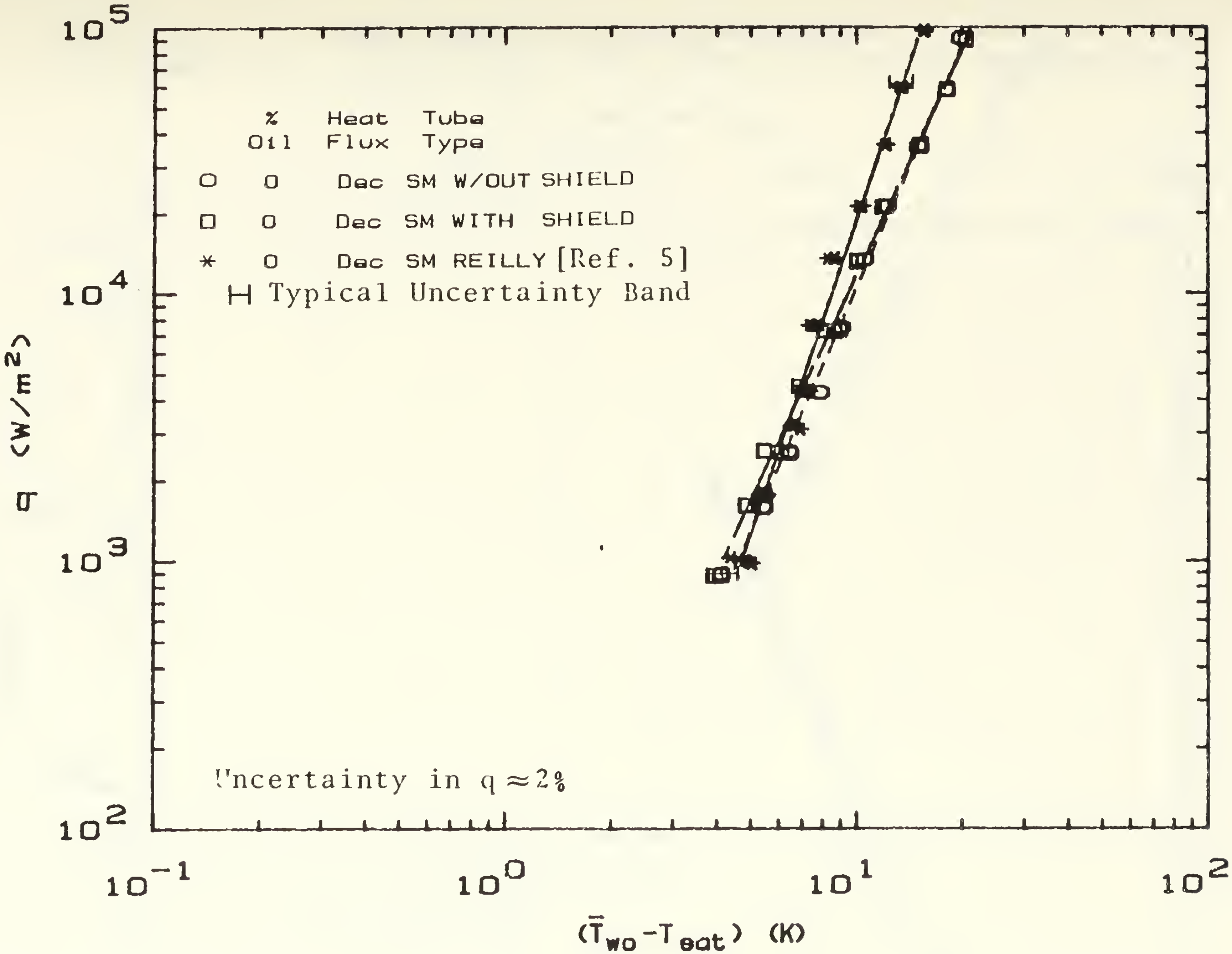


Figure 4.1 Performance Comparison for Pure R-114 Boiling from a Smooth Tube.

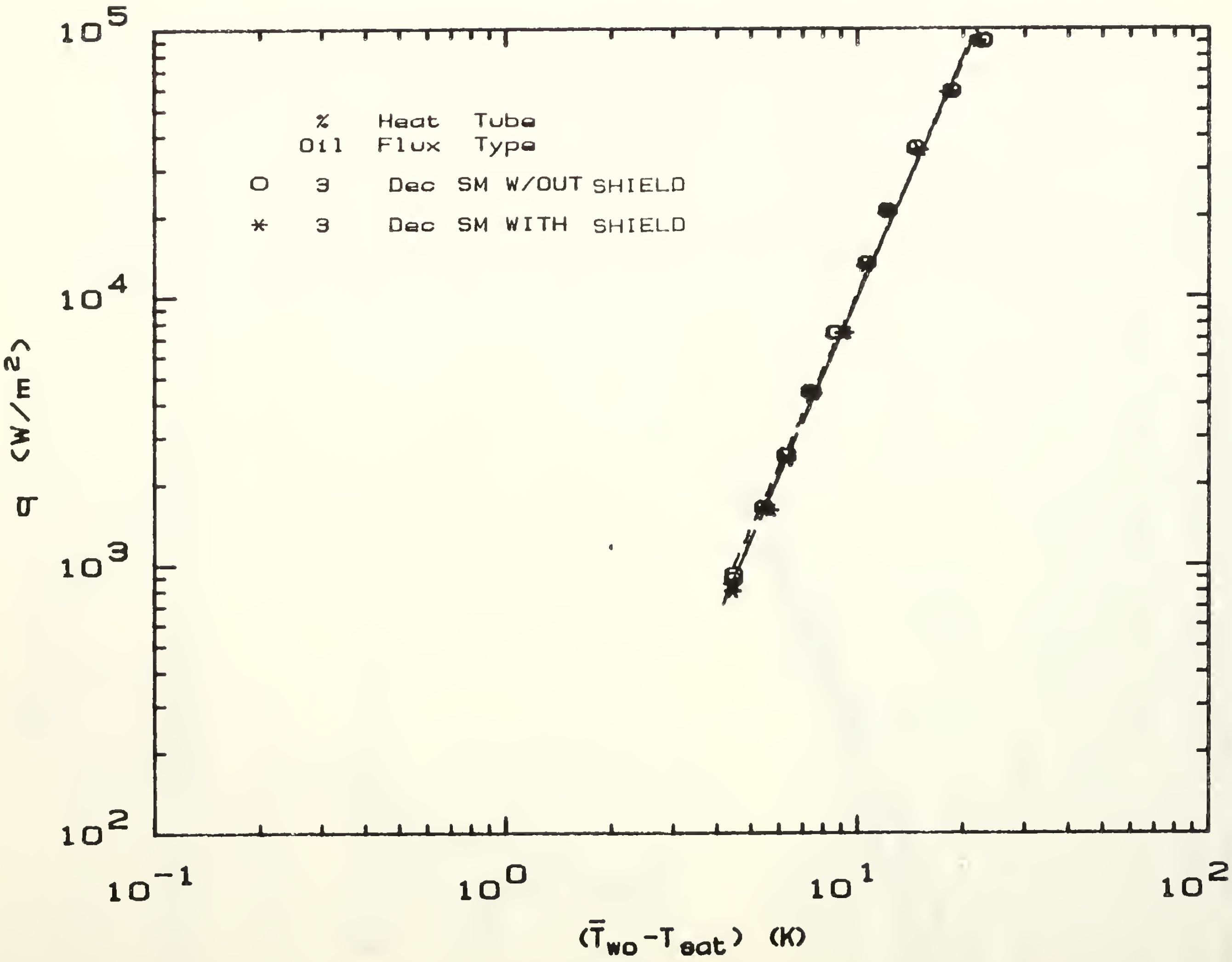


Figure 4.2 Performance Comparison for R-114 with 3 Percent Oil Boiling from a Smooth Tube.

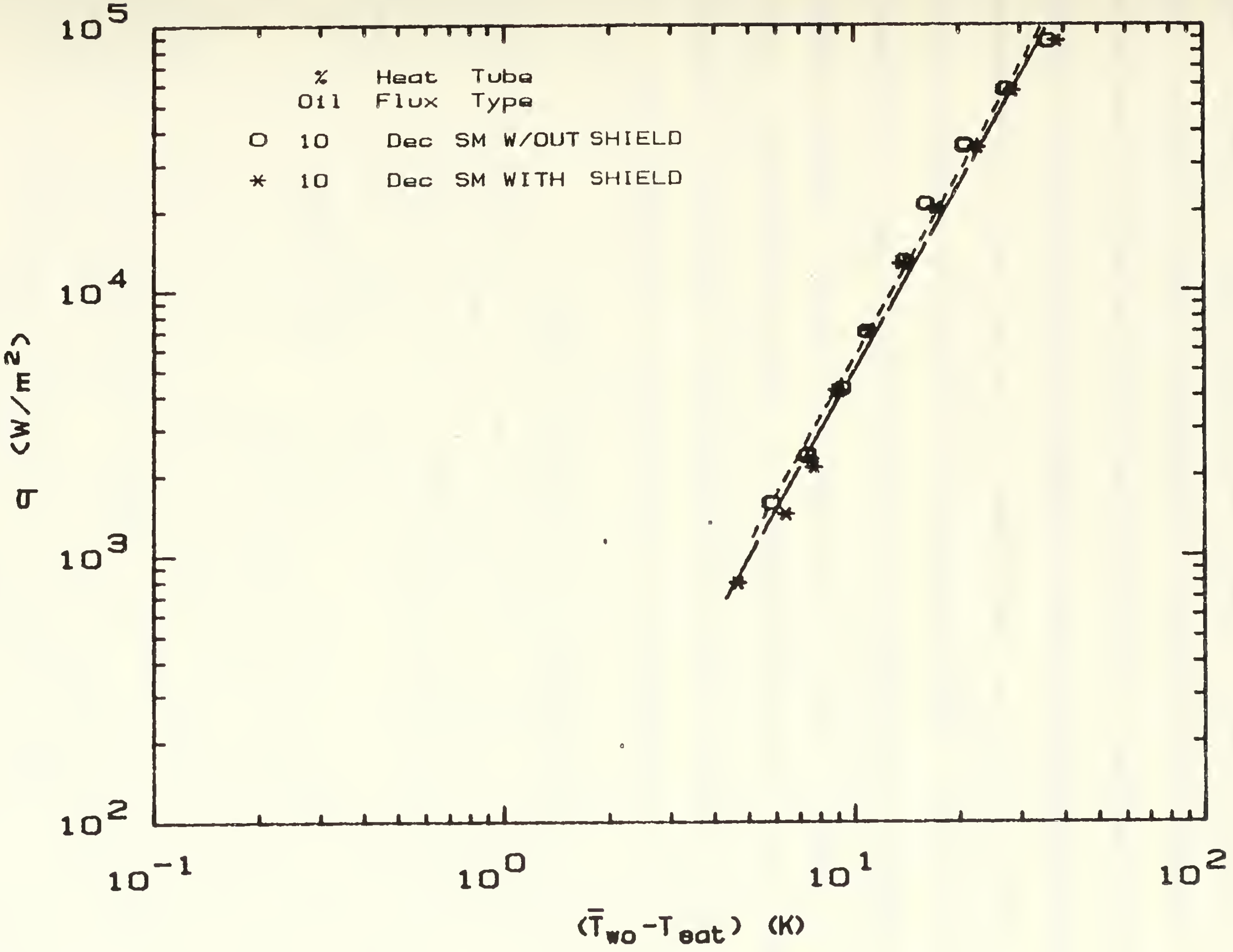


Figure 4.3 Performance Comparison for R-114 with 10 Percent Oil Boiling from a Smooth Tube.

−2.2 °C. This data set represents a series of data runs, starting with a heat flux of 100 kW/m^2 and decreasing the heat flux to a minimum of 1 kW/m^2. The three sets of curves are nearly identical with the deviation between the Reilly data and the most recent data being attributed to the pressure effect and the possible aging of the tinned interface between the thermocouple sleeve and the inner surface of the smooth copper tube. The maximum discrepancy of the computed wall superheat between Reilly's data and the present data is about twenty percent at the maximum heat-flux setting. This figure also shows the typical uncertainty of about 10 percent computed for the wall superheat values during this investigation.

B. BOILING PERFORMANCE OF THE SMOOTH TUBE

Figure 4.4 shows the performance of the smooth copper tube in pure R-114 and refrigerant-oil mixtures of 3 and 10 mass percent oil. The behavior of the smooth copper tube in pure R-114 liquid demonstrates typical nucleate pool-boiling performance. As can be seen in Figure 4.4, the line between points A and B represents a region of constant slope (on a log-log scale) for the variation of heat flux with the tube wall superheat ($\overline{T}wo$-Tsat). This section of the curve represents natural convection (i.e., no bubbles were generated).

Upon reaching point B (see Figure 4.4), the boiling tube wall superheat begins to decrease even though the heat flux is continually increased. At this point, the tube begins to demonstrate the characteristics of incipient nucleate boiling. This region is known as the mixed boiling region, where the transition from natural convection to nucleate boiling occurs. This event is characterized by the increasing number of active nucleation sites with increasing heat flux. It should be noted that during all data runs, the unheated ends of the tubes did not show any nucleation sites. Reilly [Ref. 5] also stated that the unenhanced ends of the boiling tube, at all observed heat fluxes, underwent only natural convection despite a small amount of heat axially conducted along the tube walls. It was observed that this transition from natural convection to nucleate boiling occurs very quickly, usually within a few seconds after the activation of the first nucleation site.

At the heat flux represented by point C in Figure 4.4, all the available activation sites of the boiling tube appear to be active and the wall superheat begins to increase with increasing heat flux. From point C to point D, where the heat flux is increased to a maximum of 91 kW/m^2, new activation sites are generated (maximum heat flux was limited by cartridge heater rated output).

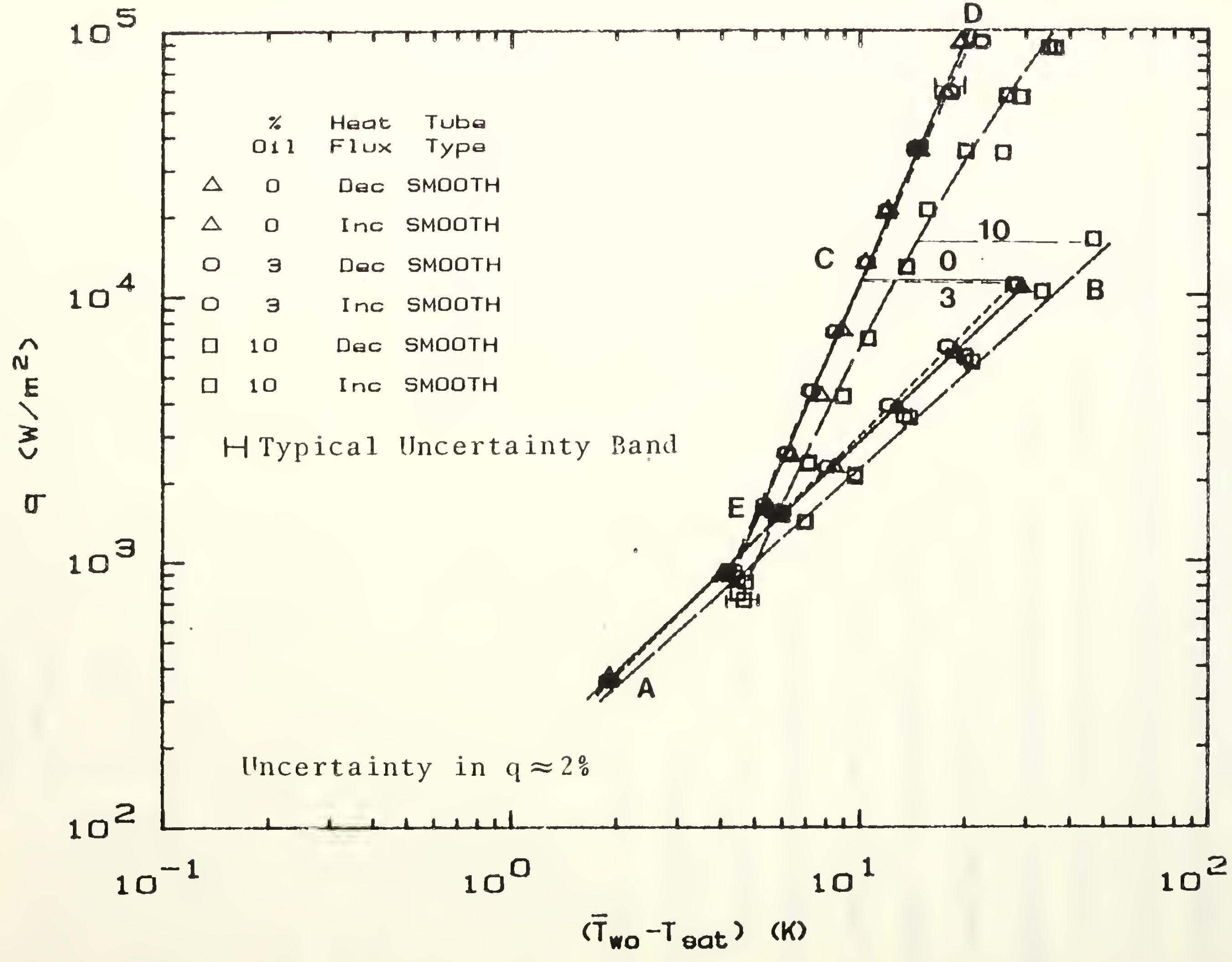


Figure 4.4 Heat-Transfer Performance for Smooth Tube in 0, 3 and 10 Percent Oil .

As the oil concentration was increased, there was a significant increase in the amount of foam generated.

After obtaining a maximum heat flux at point D, the heat flux was decreased and is represented as the region between points D and E on Figure 4.4. This region of the curve represents decreasing wall superheat; however, more activation sites that were created at the higher heat-flux settings remain active to lower heat fluxes. This increased range over which the boiling tube continues to nucleate results in an increase in the heat-transfer performance since the wall superheat temperature for the nucleate boiling at any particular heat flux is less than the tube wall superheat for the natural convection heating at the same heat flux.

Stephan [Ref. 9] reported that the effects of adding oil introduces a mass-diffusion resistance to the liquid and therefore lowers the heat-transfer coefficient. Reilly [Ref. 5], in his discussion of his smooth-tube data at a saturation temperature of -2.2°C (Figure 4.5), stated that the 3 mass percent oil and 10 mass percent oil concentrations demonstrated higher wall superheat temperature than that observed in the pure R-114 liquid. However, Reilly observed that the wall superheat for the 3 percent oil concentration was higher than that for the 10 percent oil concentration. He attributed this to the

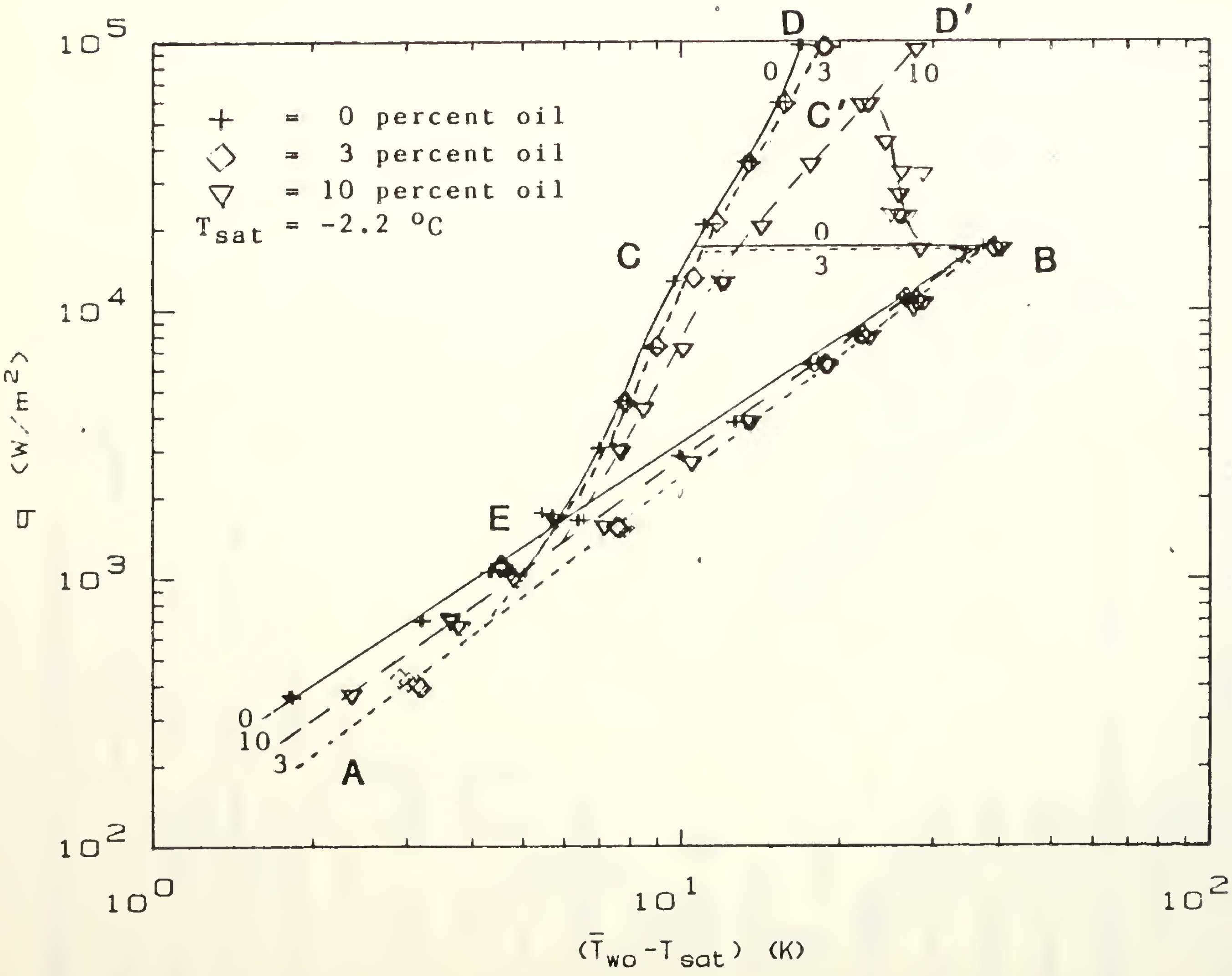


Figure 4.5 Reilly's [Ref. 5] Smooth Tube Data for 0, 3 and 10 Percent Oil.

non-linear physical property characteristics of the refrigerant-oil mixtures. As can be seen in Figure 4.4, the general trend of the data is the same with the exception of the 3 percent oil concentration wall superheat, which nearly overlays the data for pure R-114 liquid. This deviation from the Reilly data may be due in part to the difference in the saturation temperatures. The addition of oil to the pure R-114 liquid, up to a maximum of 10 percent, should delay the transition from natural convection to nucleate pool boiling on the tube. With a refrigerant-oil mixture of 10 mass percent oil, it was observed that the surface nucleation sites did appear to spread more slowly as the heat flux was increased. This condition continued until the tube was fully engulfed in the nucleate boiling mode. This observation was also noted by Reilly [Ref. 5] and it agrees with the contention of Chongrungreong and Sauer [Ref. 8] and Thome [Ref. 6] that, with the exception of the surface tension, the non-linear variations in the physical properties of the refrigerant-oil mixtures explain the variation in the boiling heat transfer of the tube.

Figure 4.6 shows the heat-transfer coefficient of the smooth tube in refrigerant-oil mixtures, plotted as a function of heat flux. Figure 4.7 shows the same plot for Reilly's data for a saturation temperature of -2.2°C

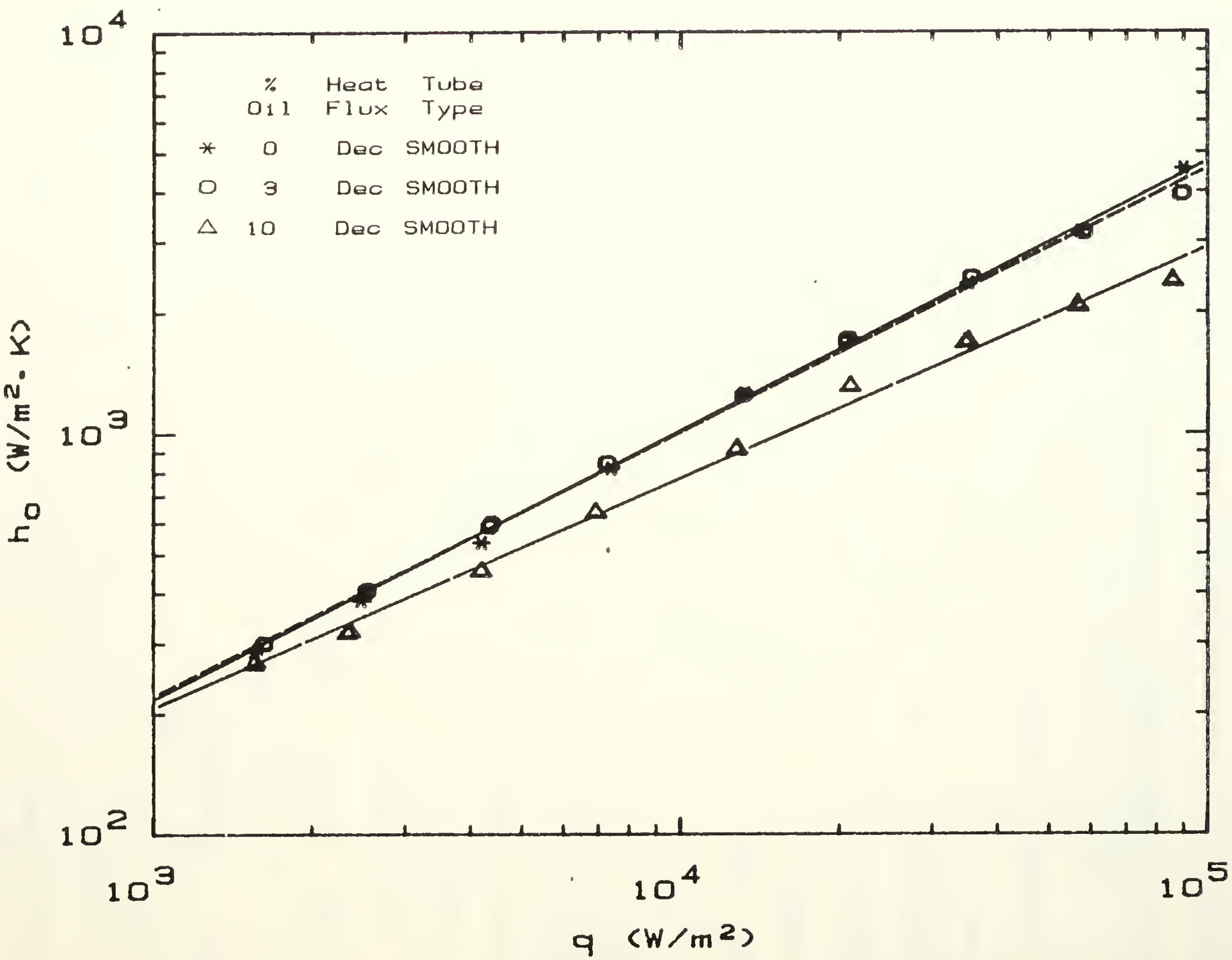


Figure 4.6 Boiling Heat-Transfer Coefficient for Smooth Tube.

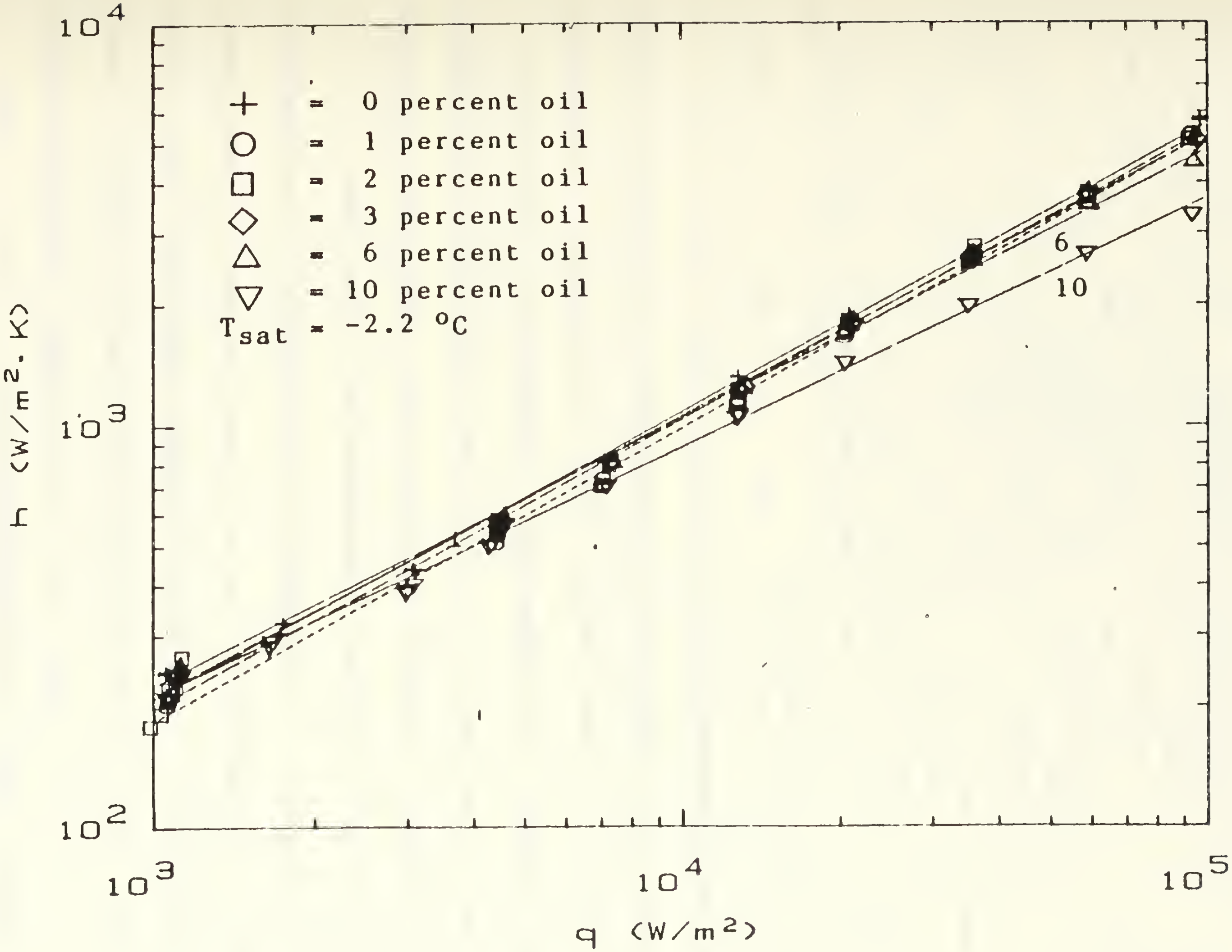


Figure 4.7 Boiling Heat-Transfer Coefficient for Reilly's Smooth Tube Data [Ref. 5]

[Ref. 5]. As can be seen, the two graphs are nearly identical, representing good repeatability of the data. Also, the effect of the addition of up to 6 percent oil (Figure 4.7) consistently represents an approximate decrease of 10 percent in the heat-transfer coefficient. As the oil concentration was increased from 6 to 10 percent, the decrease in the heat-transfer coefficient was a maximum of about 35 percent. These decreases in the heat-transfer coefficients were dependent on the comparison of the pure R-114 and the 10 percent oil concentration at equal heat-flux settings.

C. BOILING PERFORMANCE OF THE GEWA-T TUBE

Figure 4.8 shows the nucleate pool-boiling performance of the GEWA-T (1.02 fins/mm) tube in R-114-oil mixtures. The magnitude of the tube-wall superheat was considerably less than the values obtained for the smooth tube discussed in Section IV.B. This lower wall superheat can be attributed to the specially formed fins of the GEWA-T tube. The performance of the GEWA-T tube is similar to that of the smooth tube with the curves of the increasing heat flux to the point of incipient nucleate boiling (point B), paralleling the performance of the smooth copper tube (Figure 4.4). The same condition exists throughout the entire range of decreasing heat fluxes.

The region bounded by points A and B shows the characteristic natural-convection heating behavior. The onset of incipient nucleate boiling at point B is clearly defined for the pure R-114 liquid. However, as the oil concentration was increased, the point of incipient nucleate boiling becomes less clearly defined and the region of mixed boiling (point B to C) increased with increased heat flux. It was also observed that in the region from A to B, the 3 percent oil mixture showed the smallest wall superheat and the pure refrigerant showed the highest wall superheat. The reason for this behavior is not fully known at present, but may be due to convection effects within the channels of the GEWA-T tube which are enhanced by the foaming action in the presence of oil.

The region bounded by the points C and D for the increasing heat-flux condition is indicative of fully developed nucleate pool boiling. The region between points D and E represents nucleate pool boiling for decreasing heat flux. Figure 4.8 shows that, as the oil concentration was increased, the wall superheat increased at a given heat flux. This is contrary to the results for the condition of increasing heat flux in the region of natural-convection heating.

When comparing the performance of the smooth tube (Figure 4.4) to that of the GEWA-Tube (Figure 4.8), the

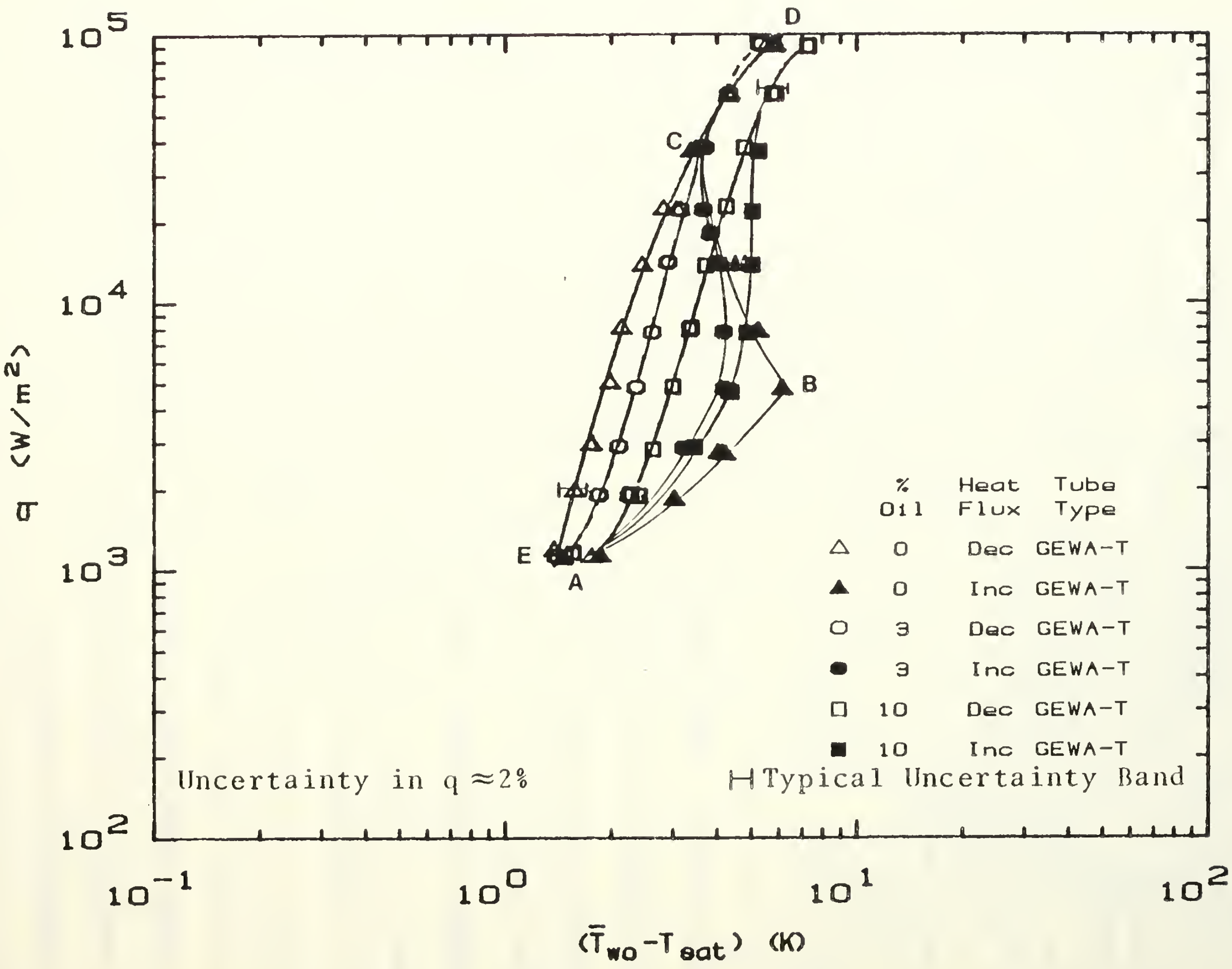


Figure 4.8 Heat-Transfer Performance for GEWA-T Surface.

maximum adverse effect of the increased oil content for the smooth tube, occurs at the higher heat-flux settings. For the GEWA-T tube, the maximum decrease in the tube performance for increased oil content, occurs in the lower and intermediate heat-flux range.

Figure 4.9 shows the heat-transfer coefficient as a function of heat flux over the range of R-114-oil mixtures (0, 1, 2, 3, 6 and 10 percent oil). Data observed over the range of R-114-oil mixtures of 1, 2, 3 and 6 percent oil are nearly coincident. The 10 percent oil concentration data represent an approximate 30 percent reduction of the heat-transfer coefficient when compared to the heat-transfer coefficient obtained during the data for pure R-114. Figure 4.10 shows the direct comparison of the GEWA-T tube with the smooth tube for R-114-oil mixtures of 0, 3 and 10 percent oil. The GEWA-T tube represents an overall enhancement of 4.2 over the baseline smooth copper tube at a heat flux of 40 kW/m^2 with pure R-114 and an overall enhancement of 3.8 with 10 percent oil. These results compare favorably with the results of Yilmaz, Hwalek and Westwater [Ref. 18] for a 12.3-mm OD GEWA-T tube in p-xylene, in which they obtained an enhancement of 5.3 in the pool-boiling heat-transfer coefficient over their baseline smooth copper tube. Additionally, Yilmaz and Westwater [Ref. 12] tested a similar surface in isopropyl

alcohol in which an enhancement of 2.0 was observed. Marto and Lepere [Ref. 13] tested a 17.9-mm OD GEWA-T surface in both R-113 and FC-72 and reported enhancements of 2.8 and 2.5, respectively.

Figure 4.11 shows more clearly the degradation that oil causes in the boiling heat-transfer performance for the GEWA-T tube. This figure plots the heat-transfer coefficient of the GEWA-T tube in the oil mixture relative to the heat-transfer coefficient in pure R-114 as a function of oil concentration. From the shape of the curves, the oil-caused degradation does not show a clear trend with the oil concentration at all practical heat fluxes. Over the range of oil concentrations, except at a heat flux setting of 37 kW/m^2, there is only a small degradation (up to a maximum of 35%) in the boiling performance. This is probably due to the large channels and reentrant cavities in the tube, allowing the "pumping" action of the bubbles to continue to remove the oil-rich liquid throughout the entire heat-flux range without a significant reduction in performance. The only significant decrease in performance occurred at heat fluxes greater than 5 kW/m^2 with 10 percent oil.

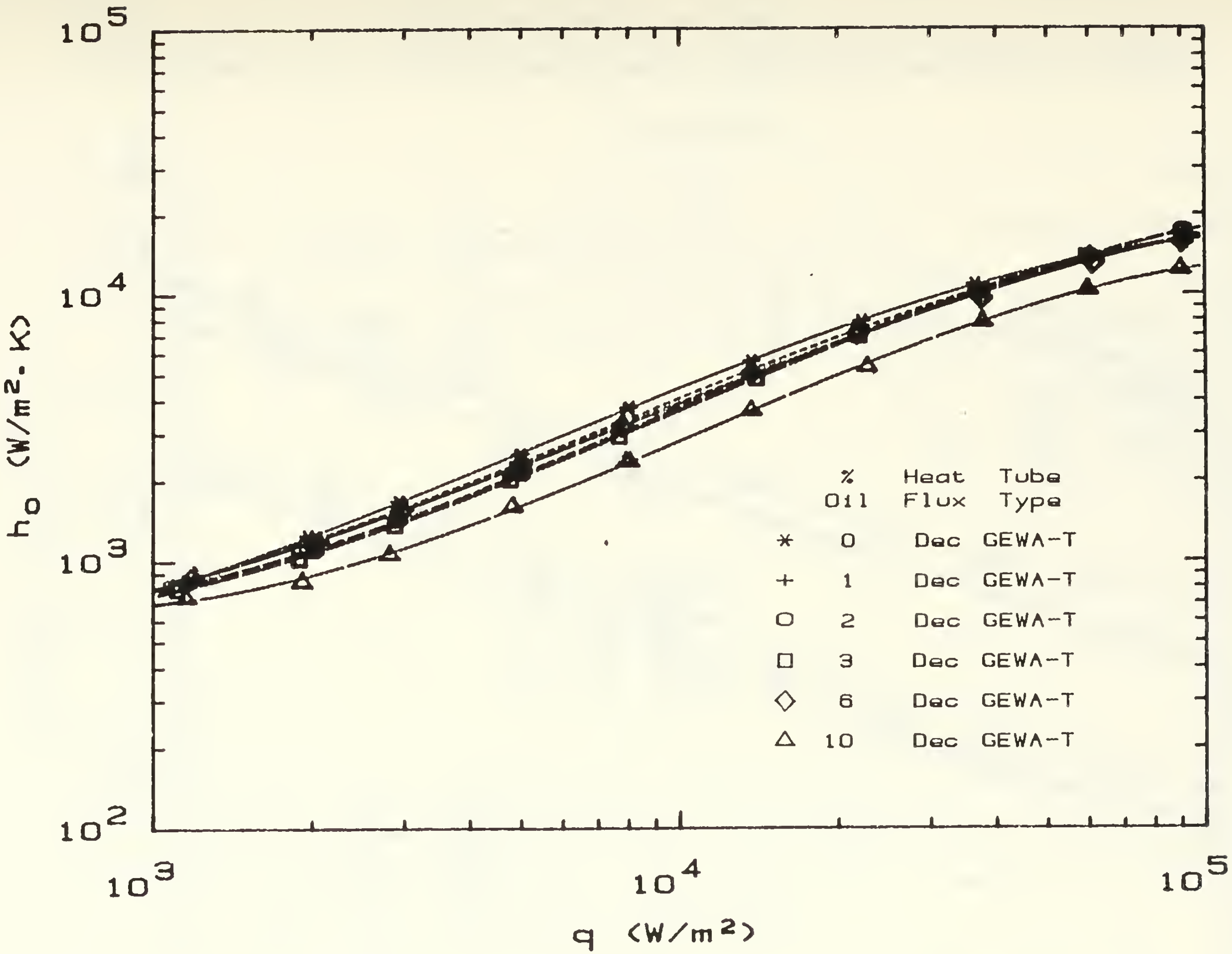


Figure 4.9 Boiling Heat-Transfer Coefficient for GEWA-T Surface.

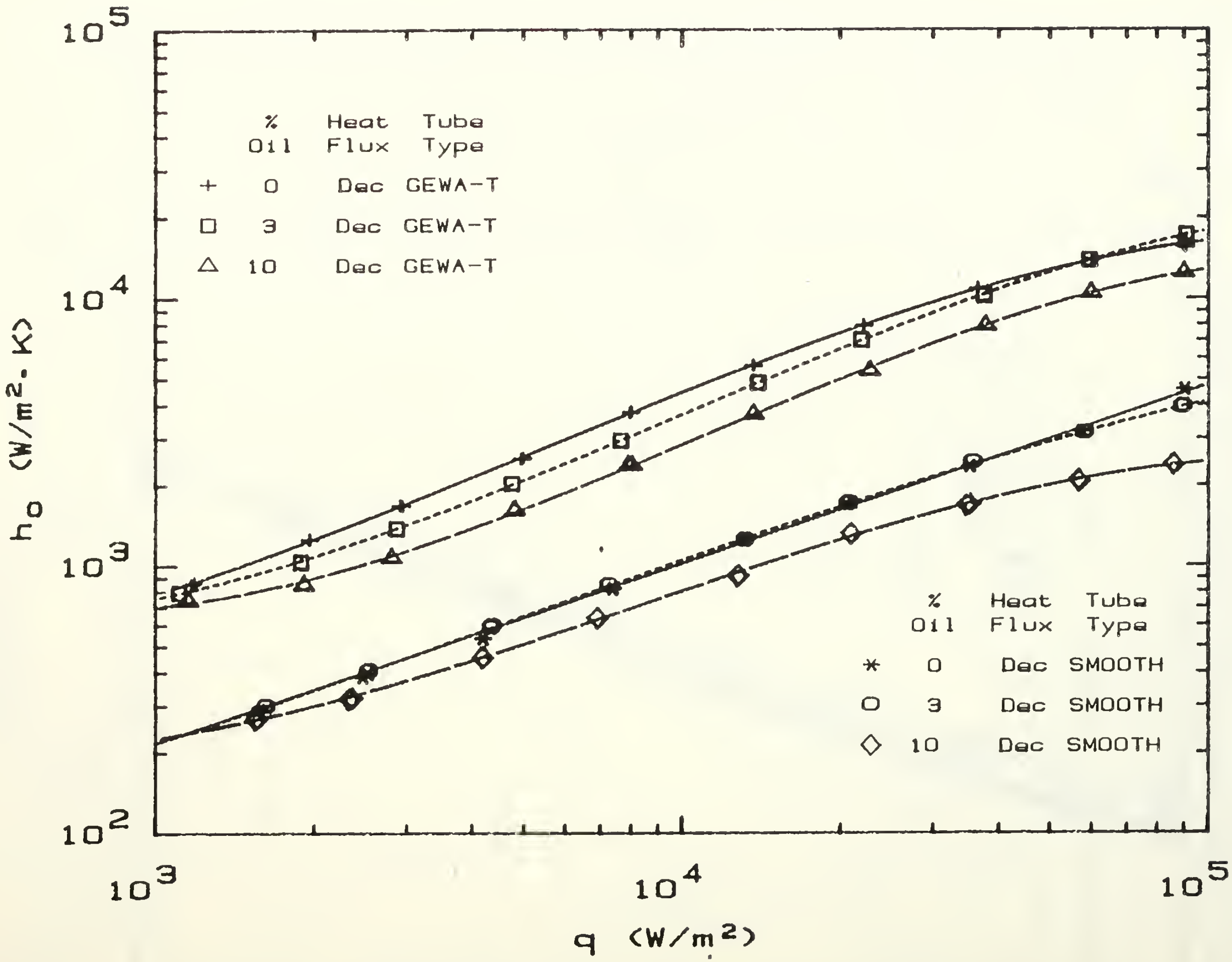


Figure 4.10 Boiling Heat Transfer Coefficient Comparison for GEWA-T Surface and Smooth Surface .

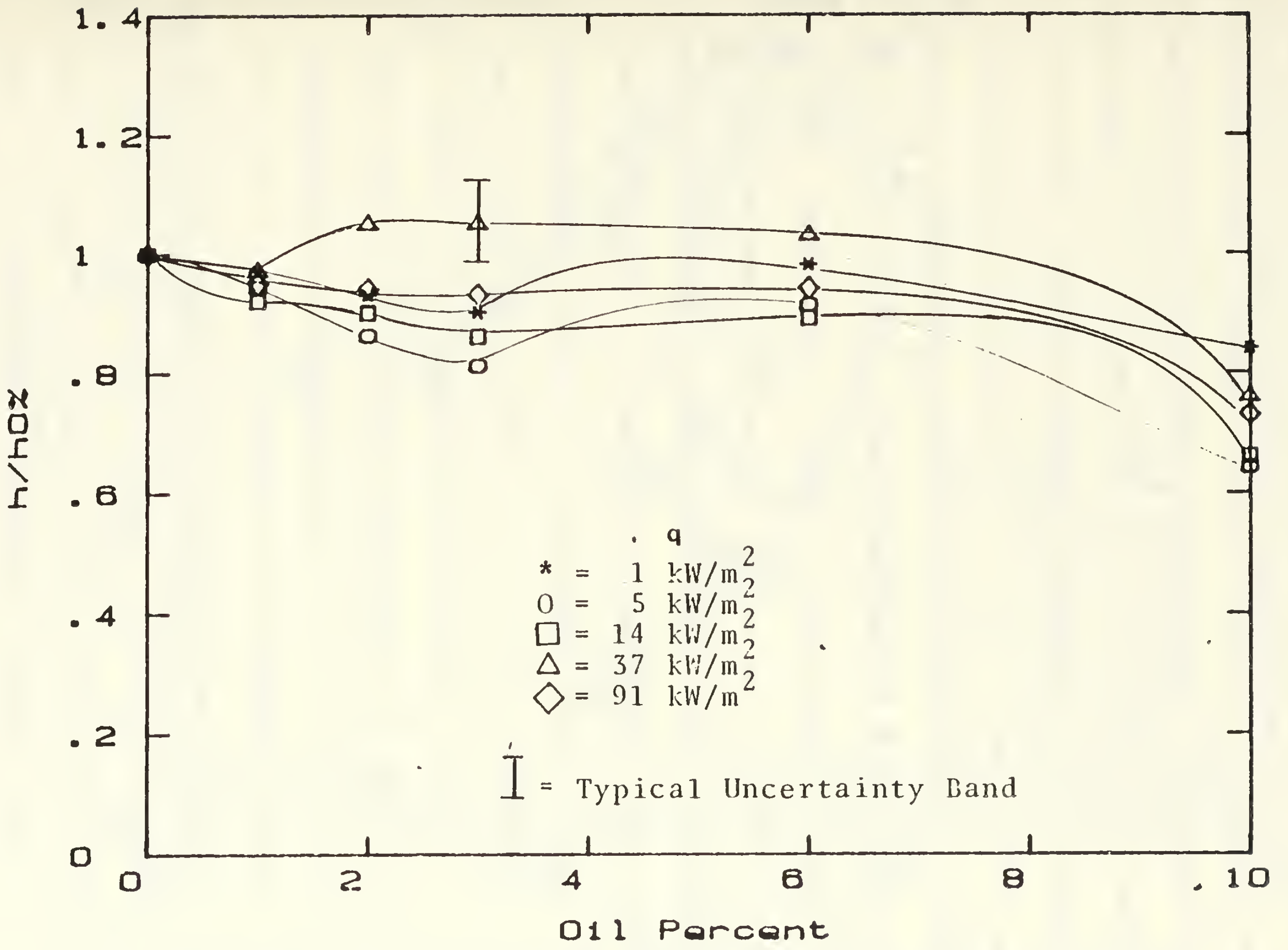


Figure 4.11 Relative Effect of Oil on GEWA-T Boiling Heat-Transfer Performance.

D. BOILING PERFORMANCE OF THE THERMOEXCEL-E TUBE

Figure 4.12 shows the nucleate pool-boiling performance of the Thermoexcel-E tube in R-114-oil mixtures. As can be seen in the figure, the region of natural-convection heating for the condition of increasing heat flux, points A to B, for the pure R-114 is very small, with the point of incipient nucleate boiling occurring at a reasonably low heat flux (1.5 kW/m^2). At this point of incipient nucleate boiling, the tube performs in the mixed boiling region as a limited number of nucleation sites become active. From point C to C', the tube appears to operate in more of a natural-convection heating mode as no new nucleation sites are activated, although previously activated sites continue to nucleate. This phenomenon is probably due to the inability of the cartridge heaters to produce uniform heat flux at these lower settings. At point C' with a heat-flux setting of 5 kW/m^2, more nucleation sites are generated and as the heat flux is increased to 60 kW/m^2, the tube becomes fully nucleated.

For the 3 percent oil concentration, the point of incipient nucleate boiling, point B', decreases as the non-linear physical properties of the R-114-oil mixture allow the onset of the mixed boiling region to occur. Also, the region of the mixed boiling, point B' to D', is

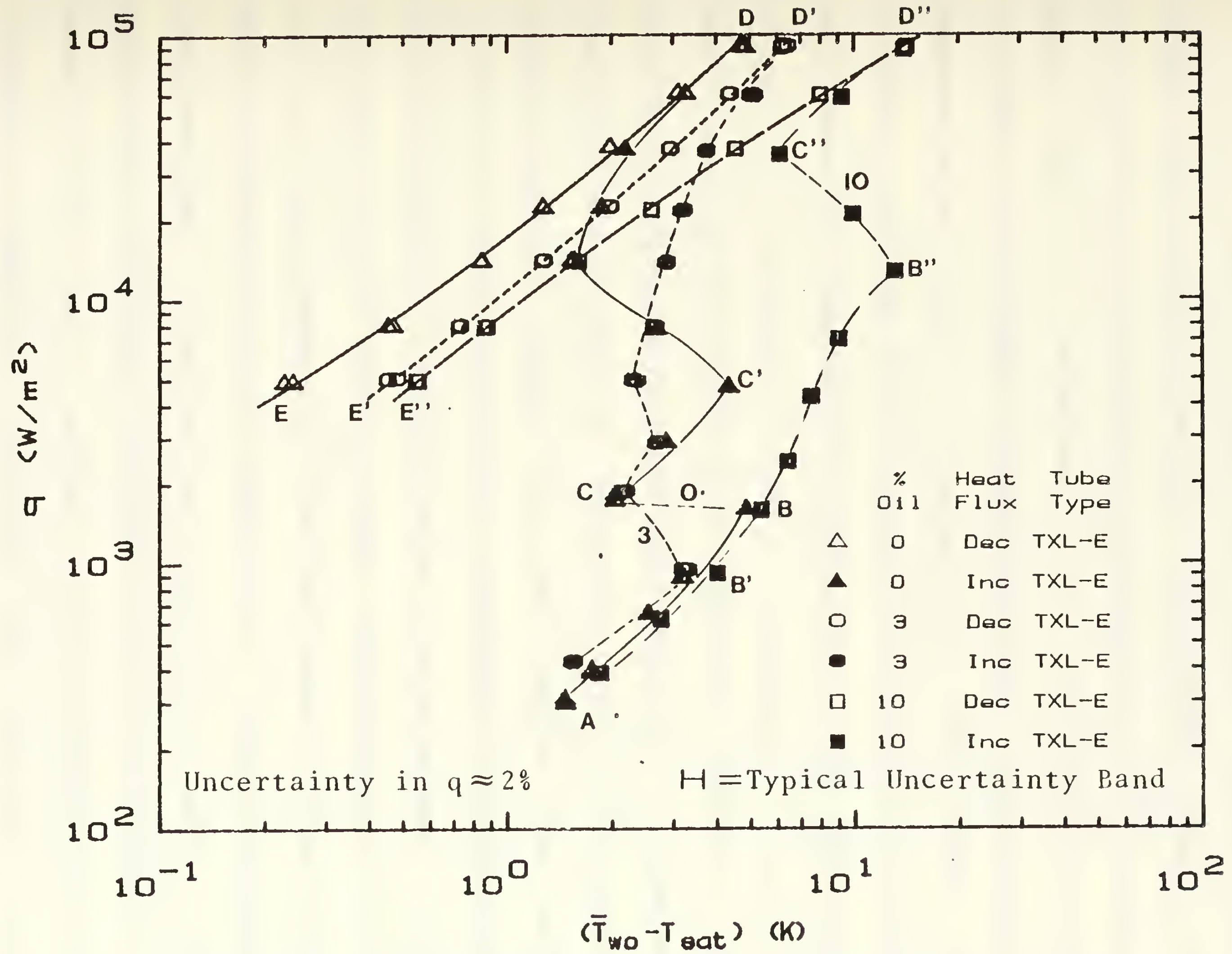


Figure 4.1 2/2 Heat-Transfer Performance for Thermoexcel-E Surface.

far larger than that for pure R-114, as the generation of new nucleation sites is retarded by the increased oil content.

For the 10 percent oil concentration, on the other hand, the point of incipient nucleate boiling, point B'', is delayed considerably. At approximately 14 kW/m^2, the transition from natural-convective heating to nucleate boiling occurs. The exact reason for the difference between the 3 percent and 10 percent behavior is not known, however it is possibly due to the change in the physical properties of the R-114-oil mixture.

The region of nucleate pool boiling for the condition of decreasing heat flux represented by points D to E, D' to E' and D'' to E'' for 0, 3 and 10 percent oil concentrations, respectively, for the Thermoexcel-E tube, represent classic nucleate pool-boiling characteristics. As the oil concentration increases, the wall superheat also increases throughout the range of heat-flux settings. At the lower heat fluxes, the largest increase in the wall superheat occurred at 3 percent oil concentration when compared to the pure R-114, while the 10 percent oil concentration was observed to undergo continual degradation in tube performance over the entire range of heat-flux settings, although a more noticeable reduction occurred at the higher heat fluxes. At a heat-flux setting of 91

kW/m², the R-114-oil mixture of 10 percent oil was observed to undergo a reduction in tube performance by a factor of 3. For the practical heat-flux range of 30 to 40 kW/m², there is an increase in wall superheat by factors of 1.4 and 2.6 for R-114-oil mixtures of 3 and 10 percent, respectively.

Figure 4.13 shows the heat-transfer coefficient of the Thermoexcel-E tube in refrigerant-oil mixtures, plotted as a function of heat flux. As can be seen in the figure, the heat-transfer coefficient remains nearly constant throughout the range of heat-flux settings for pure R-114, while there are slight reductions for the 1, 2 and 3 percent oil concentrations. Additionally, it can be seen that at these lower oil concentrations, the heat-transfer coefficients are nearly coincident. As the R-114-oil mixture oil concentration is increased to 6 percent, the tube performance increases with increasing heat flux until reaching a heat-flux setting of 60 kW/m², at which time tube performance begins to deteriorate. This is contrary to the tube performance for 0, 2, and 3 percent oil concentrations in which the heat-transfer coefficient was observed to increase slightly over the range of heat fluxes. For the 10 percent oil concentration, the heat-transfer coefficient decreased as the heat flux was increased.

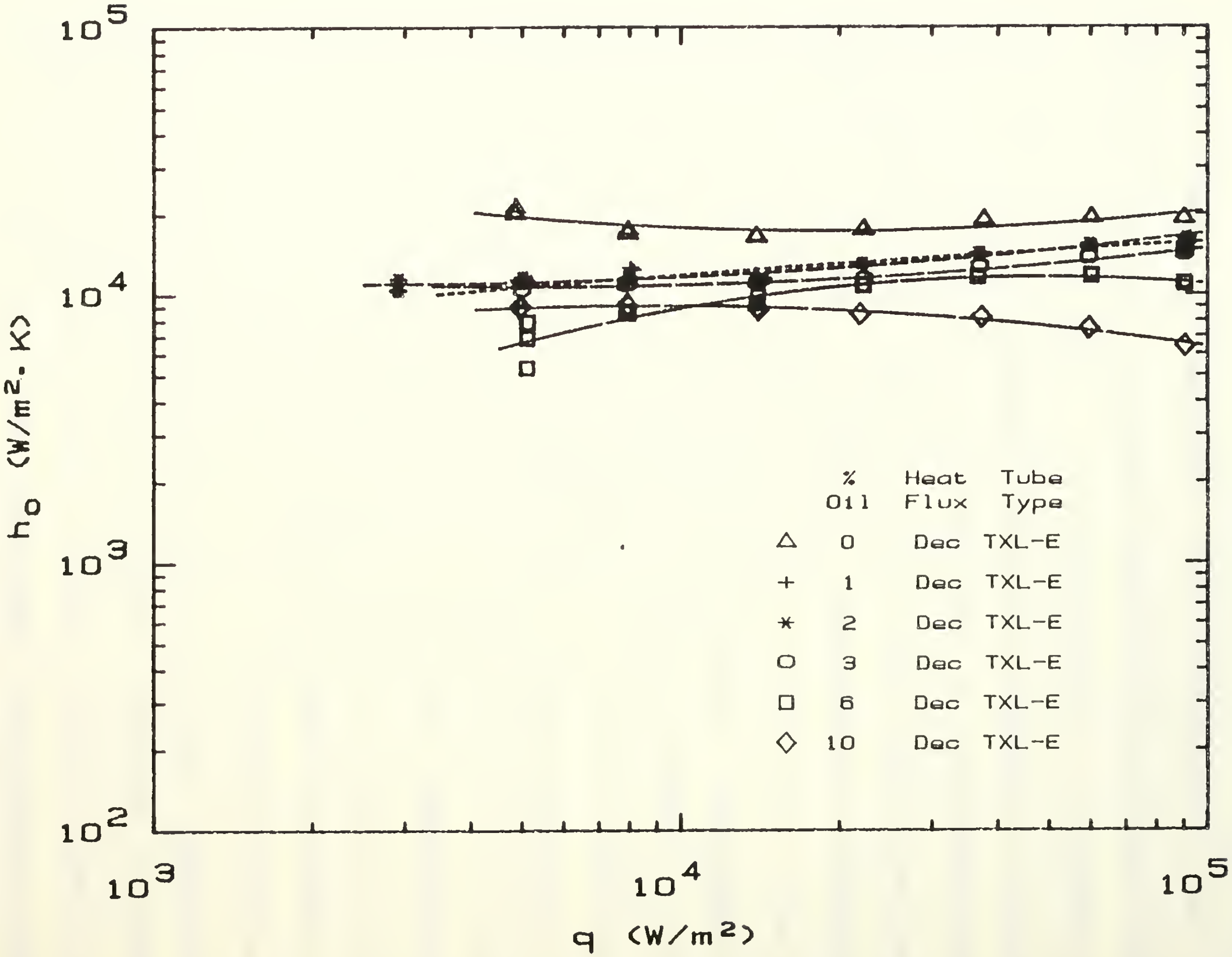


Figure 4.13 Boiling Heat-Transfer Coefficient for Thermoexcel-E Surface .

Figure 4.14 shows a direct comparison of the Thermoexcel-E tube to the smooth copper tube for R-114-oil mixtures of 0, 3 and 10 percent. The Thermoexcel-E tube presents enhancements of 6.6 and 4.1 over the performance of the smooth copper tube in pure R-114 and an R-114-oil mixture of 10 percent oil, respectively, at a heat-flux setting of 40 kW/m^2. The results for the pure R-114 compare favorably with the results obtained by Yilmaz, Palen and Taborek [Ref. 19] for the Thermoexcel-E in p-xylene.

Figure 4.15 shows the degradation that oil causes in the boiling heat-transfer performance for the Thermoexcel-E tube. This figure plots the ratio of the heat-transfer coefficient of the Thermoexcel-E tube with oil to the value without oil as a function of oil concentration. The shapes of the curves continue to demonstrate the non-linear variation of the physical properties of refrigerant-oil mixtures. However, the significant degradation of the tube performance is probably due to the inability of the generated bubbles to scavenge the interior tunnels of the Thermoexcel-E tube. This is in contrast to the GEWA-T tube, where more scavenging is possible due to its larger channel size.

E. BOILING PERFORMANCE OF THE THERMOEXCEL-HE TUBE

Figure 4.16 shows the nucleate pool-boiling performance of the Thermoexcel-HE tube in R-114-oil

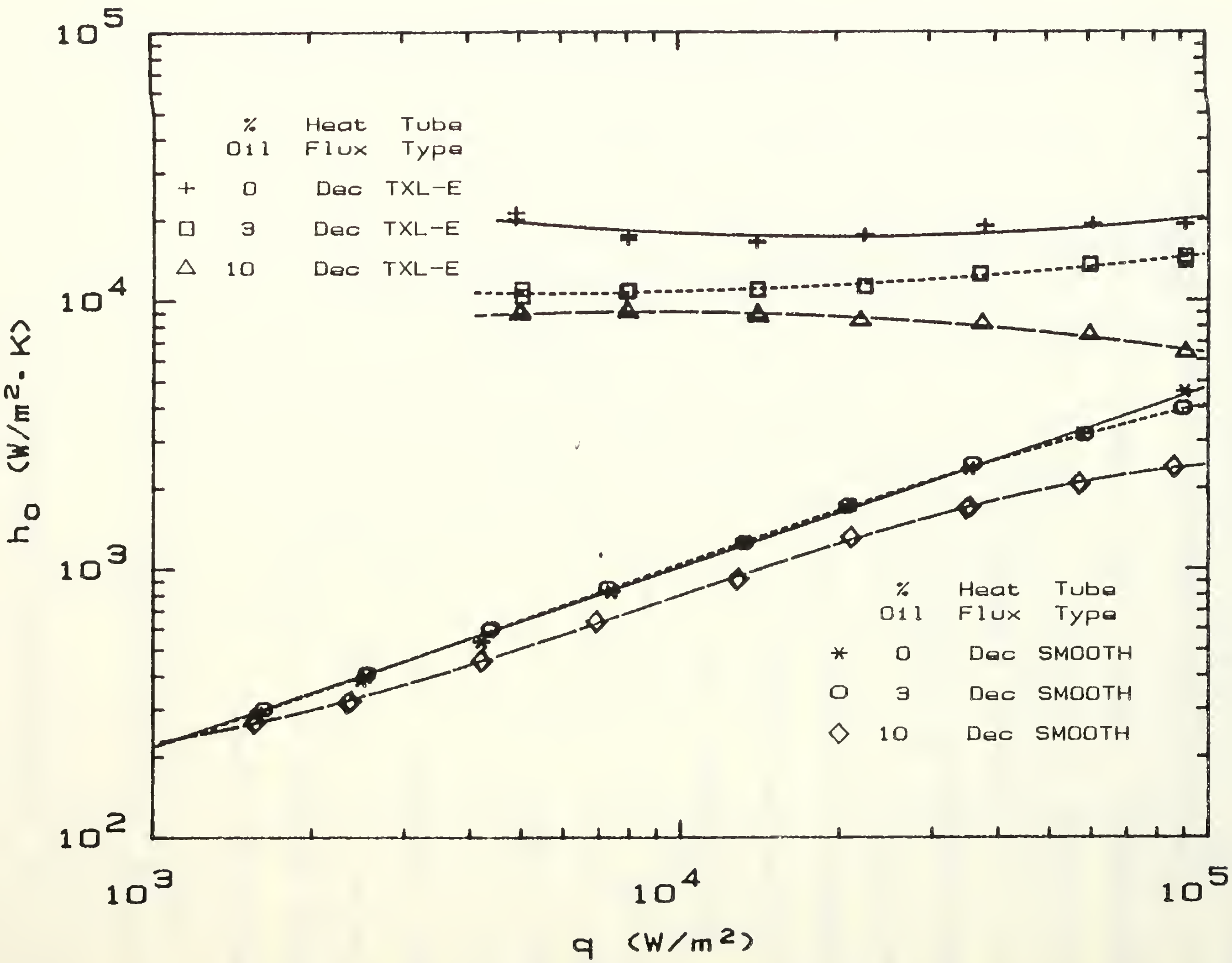


Figure 4.14 Boiling Heat-Transfer Coefficient for Thermoexcel-E vs. Smooth Surface.

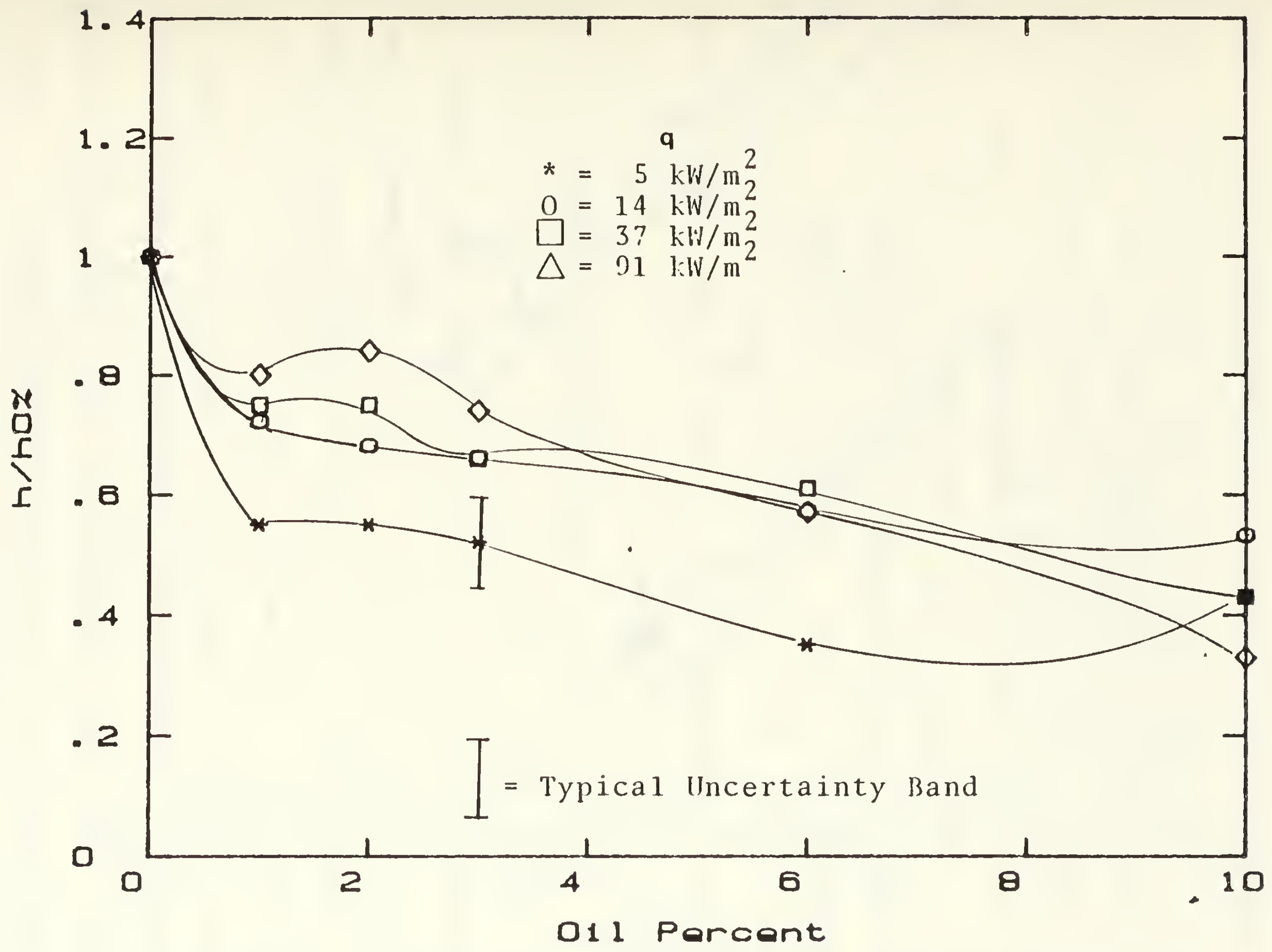


Figure 4.15 Relative Effect of Oil On Thermoexcel-E Boiling Heat-Transfer Performance.

mixtures. In the region between points A and B/B', natural-convection heating occurs for increasing heat flux. Although similar in performance to the Thermoexcel-E tube, the Thermoexcel-HE tube presented a more linear characteristic than that of the Thermoexcel-E tube, representing a more uniform heat distribution. At point B on the figure, the point of incipient nucleate boiling for pure R-114 liquid occurs at approximately 2 kW/m^2. For R-114-oil mixture of 3 and 10 percent oil concentrations, the point of incipient nucleate boiling, point B', occurs at approximately 8 kW/m^2. Also in this region, the pure R-114 and the R-114-oil mixture of 3 percent oil concentration are nearly coincident in the range of heat flux from 500 W/m^2 to 2 kW/m^2.

From points B to C, the Thermoexcel-HE tube in the pure R-114 liquid achieved full nucleate boiling at approximately 37 kW/m^2, with intermediate data points in the region of mixed boiling. These intermediate data points indicate that the Thermoexcel-HE tube was not able to activate all nucleation sites simultaneously for increasing heat-flux conditions. The R-114-oil mixture of 10 percent oil was able to achieve activation of all nucleation sites upon reaching 22 kW/m^2, without any data points contained in the mixed boiling region. With 3 percent oil, the Thermoexcel-HE tube was able to achieve

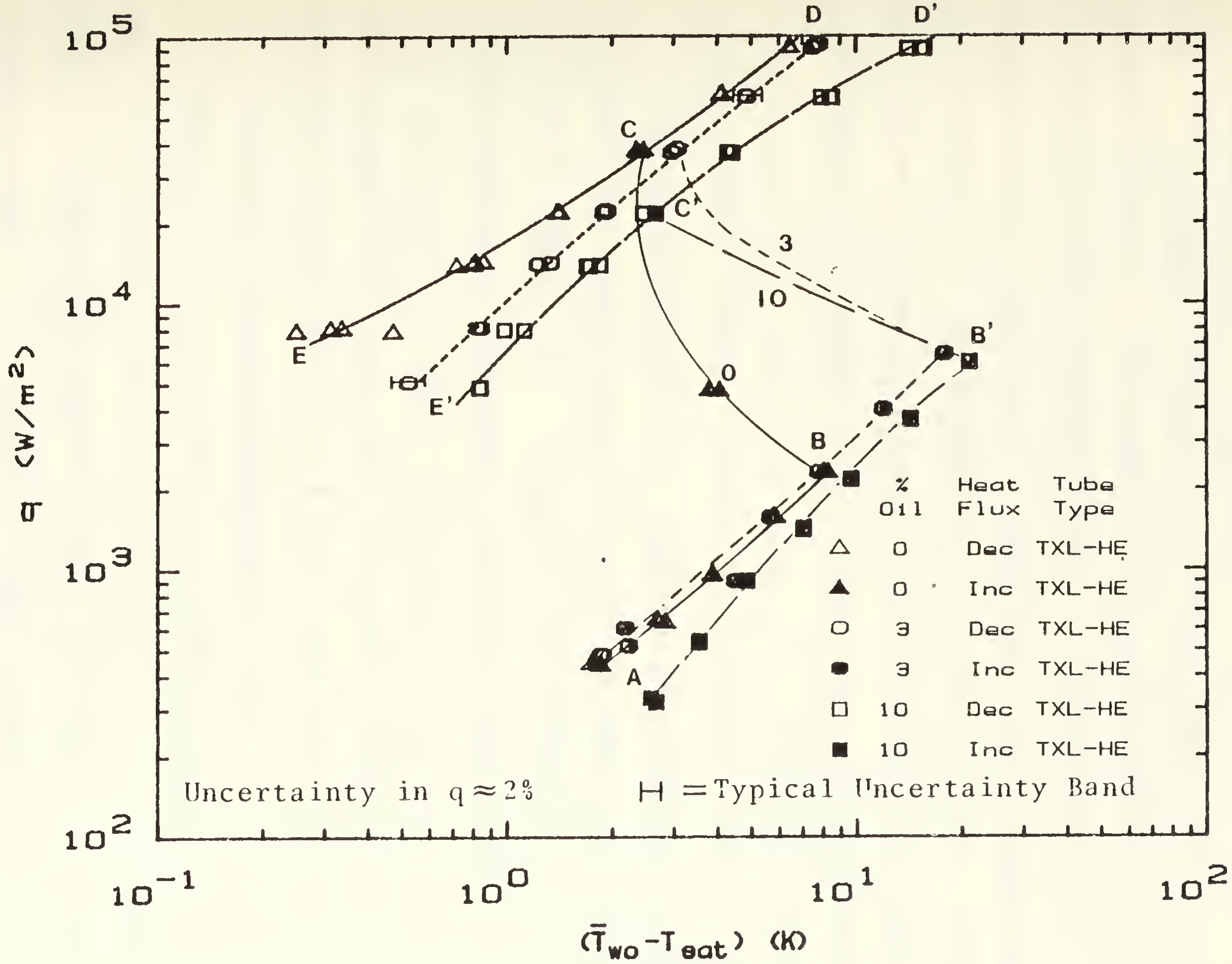


Figure 4.16 Heat-Transfer Performance for Thermoexcel-HE Surface .

full nucleate boiling at 37 kW/m². The Thermoexcel-HE tube in the R-114-oil mixtures appeared to activate all nucleation sites simultaneously.

The region from points C to D and from C' to D' represent the nucleate pool boiling for increasing heat flux. The performance of the Thermoexcel-HE tube in this region appears to decrease as the oil content was increased. The 10 percent oil concentration increased the wall superheat by a factor of approximately 2 above the wall superheat for the pure R-114 liquid for heat-flux settings of 40 kW/m².

The regions between the points D and E and D' and E' represent nucleate pool-boiling for decreasing heat-flux conditions. As can be seen from the figure, the greatest reduction in performance occurs in the lower heat-flux settings between the pure R-114 and the 3 percent oil concentration. This is similar to the results for the Thermoexcel-E tube, where the tube performance decreased as oil content increased. There is a significant decrease in the Thermoexcel-HE tube performance over the range of heat-flux settings as the oil concentration is increased to 10 percent.

Figure 4.17 shows the heat-transfer coefficient of the Thermoexcel-HE tube in refrigerant-oil mixtures, plotted as a function of heat flux. As can be seen, the performance is very similar to that of the Thermoexcel-E

tube (Figure 4.13). As was observed for the Thermoexcel-E tube, the Thermoexcel-HE tube undergoes a slight reduction in the heat-transfer coefficient as the oil concentration was increased from 1 to 3 percent. As the oil concentration is increased to 6 and 10 percent oil, the performance reduction is quite noticeable. With the 10 percent oil concentration, tube performance decreases at both the lower and higher heat-flux settings. This is contrary to the findings for the Thermoexcel-E tube where the performance decreased over the entire range of heat-flux settings, from low heat flux to high heat-flux settings.

Figure 4.18 shows a comparison of the Thermoexcel-HE tube to the smooth copper tube at R-114-oil mixtures of 0, 3 and 10 percent oil concentrations. The Thermoexcel-HE tube displayed an enhancement of 6.1, 4.6 and 4.1 at a heat flux setting of 40 kW/m^2 and R-114-oil mixtures of 0, 3 and 10 percent oil, respectively, over the same parameters for the smooth copper tube. These results are nearly identical to those found for the Thermoexcel-E tube.

Figure 4.19 shows the degradation that the oil has on the boiling heat-transfer performance of the Thermoexcel-HE tube. At the lower heat fluxes, the effect of the oil concentration is slightly more pronounced than that observed for the Thermoexcel-E tube throughout the range of

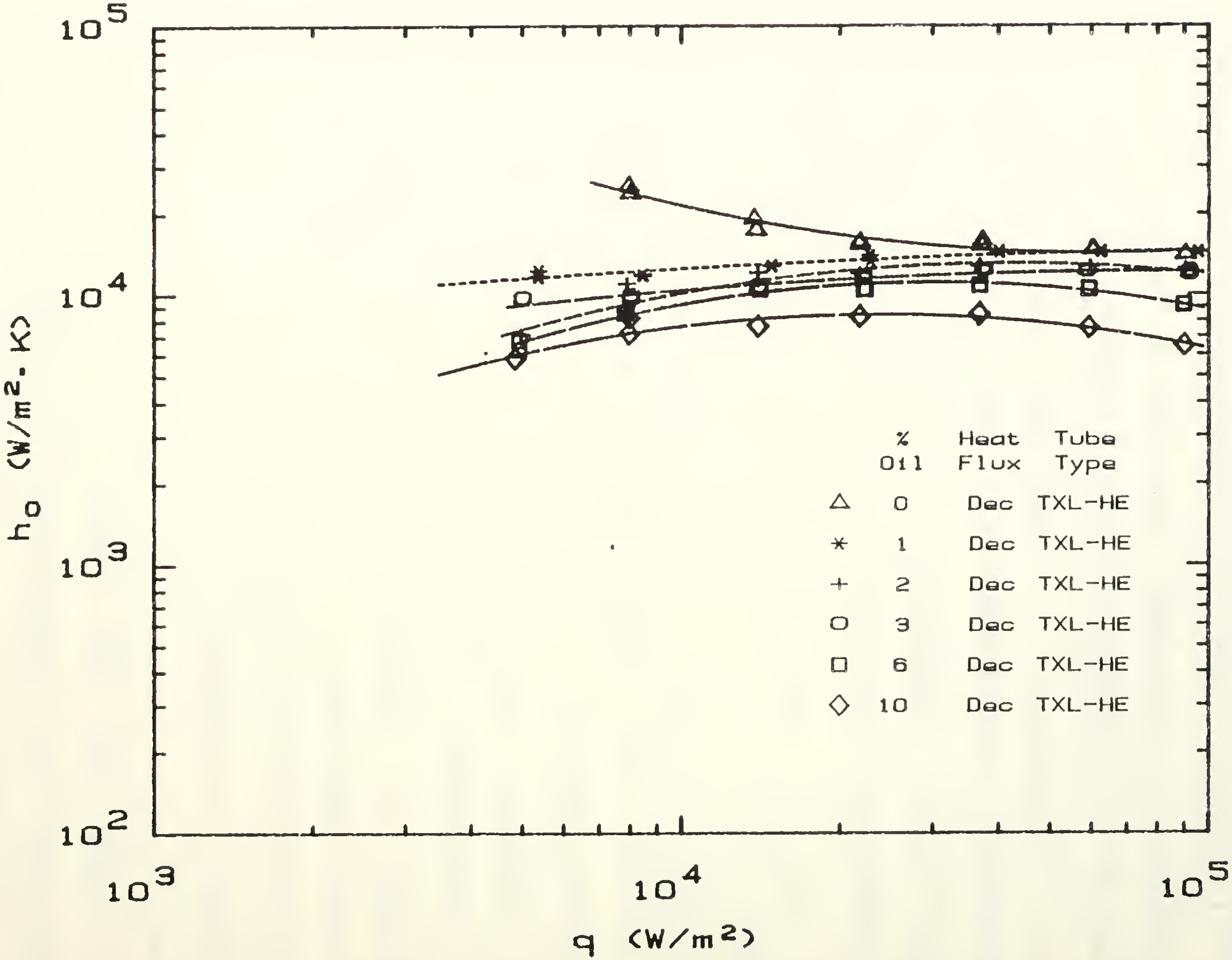


Figure 4.17 Boiling Heat-Transfer Coefficient for Thermoexcel-HE.

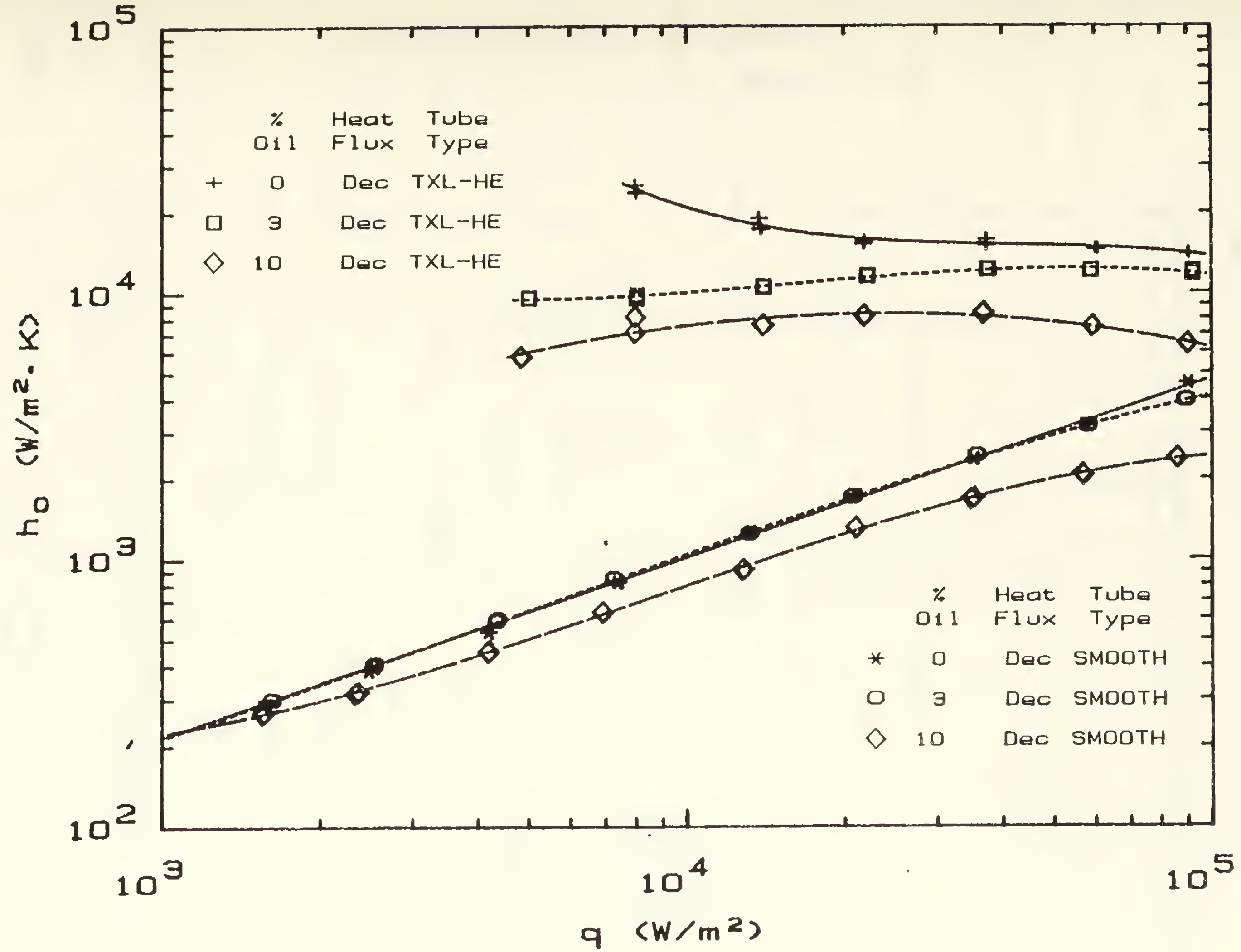


Figure 4.18 Boiling Heat-Transfer Coefficient Comparison for Thermoexcel-HE Surface vs. Smooth Surface .

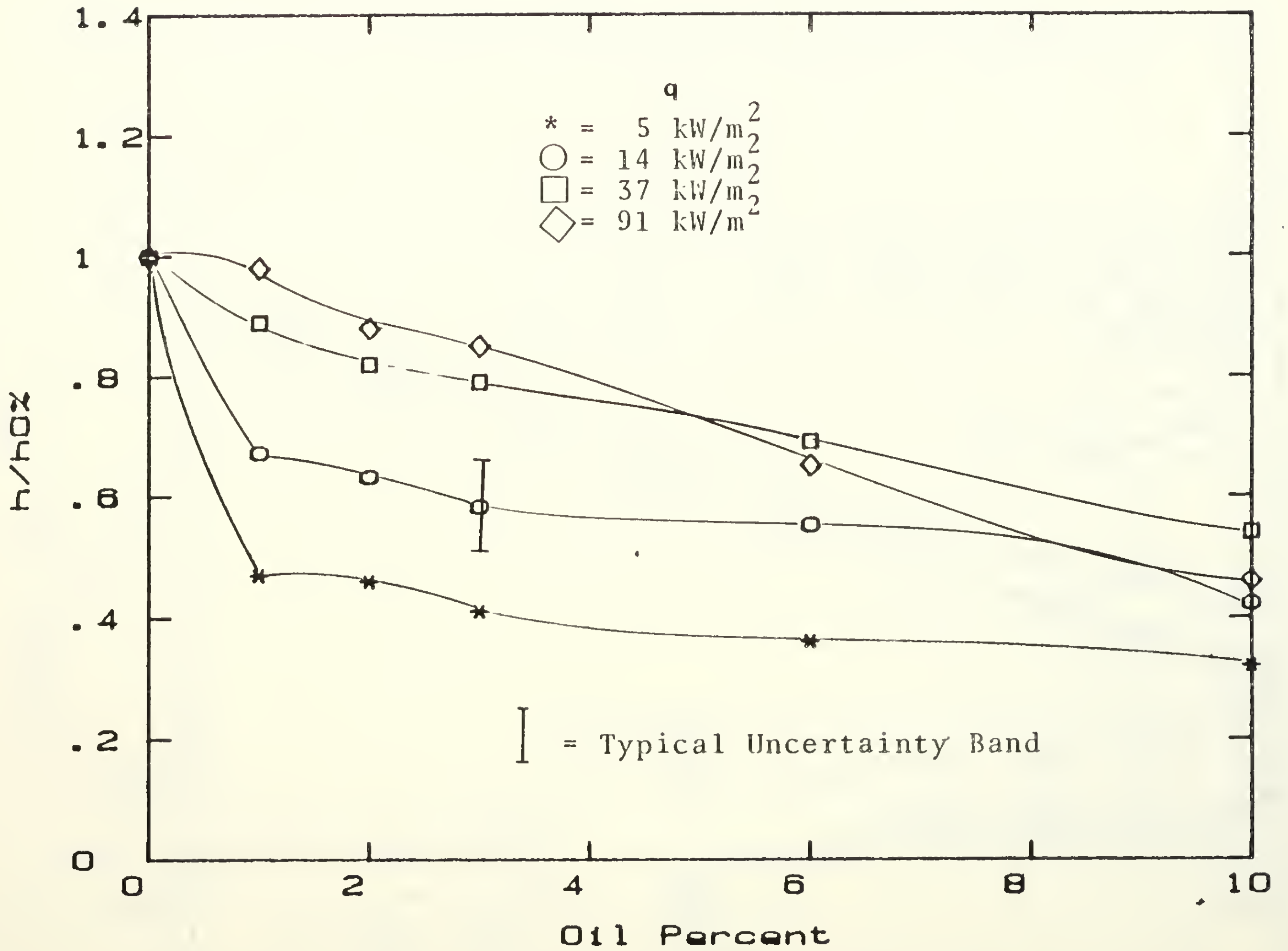


Figure 4.19 Relative Effect of Oil on Thermoexcel-HE Boiling Heat-Transfer Performance.

oil concentrations, although more severe at the lower oil concentrations. At the higher heat fluxes, the trend appears to reverse.

F. COMPARISON TO REILLY'S DATA FOR THE HIGH FLUX TUBE

Figures 4.20, 4.21 and 4.22 provide a comparison of the smooth, High Flux, GEWA-T, Thermoexcel-E and Thermoexcel-HE tubes for 0, 3 and 10 percent oil concentrations, respectively. For pure R-114 liquid, the High Flux,Thermoexcel-E and Thermoexcel-HE tubes operating at a heat flux of approximately 20 kW/m², show nearly identical performance. As the heat flux was increased, the performance of the High Flux tube continued to increase while the performance of Thermoexcel-E and Thermoexcel-HE tubes remained nearly constant. At heat-flux settings lower than 20 kW/m², the Thermoexcel-E and Thermoexcel-HE tubes showed higher heat-transfer coefficients than that for the High Flux tube. As the oil concentration was increased to 3 percent, the performance of all five tubes decreased, as can be seen in Figure 4.21. Additionally, the GEWA-T tube's performance appeared to decrease the least since, as discussed earlier in section IV.C, the finned surface of the GEWA-T tube is not adversely effected by the small increase in the oil content due to its large reentrant cavities. From this observation, it can be stated that the performance of the

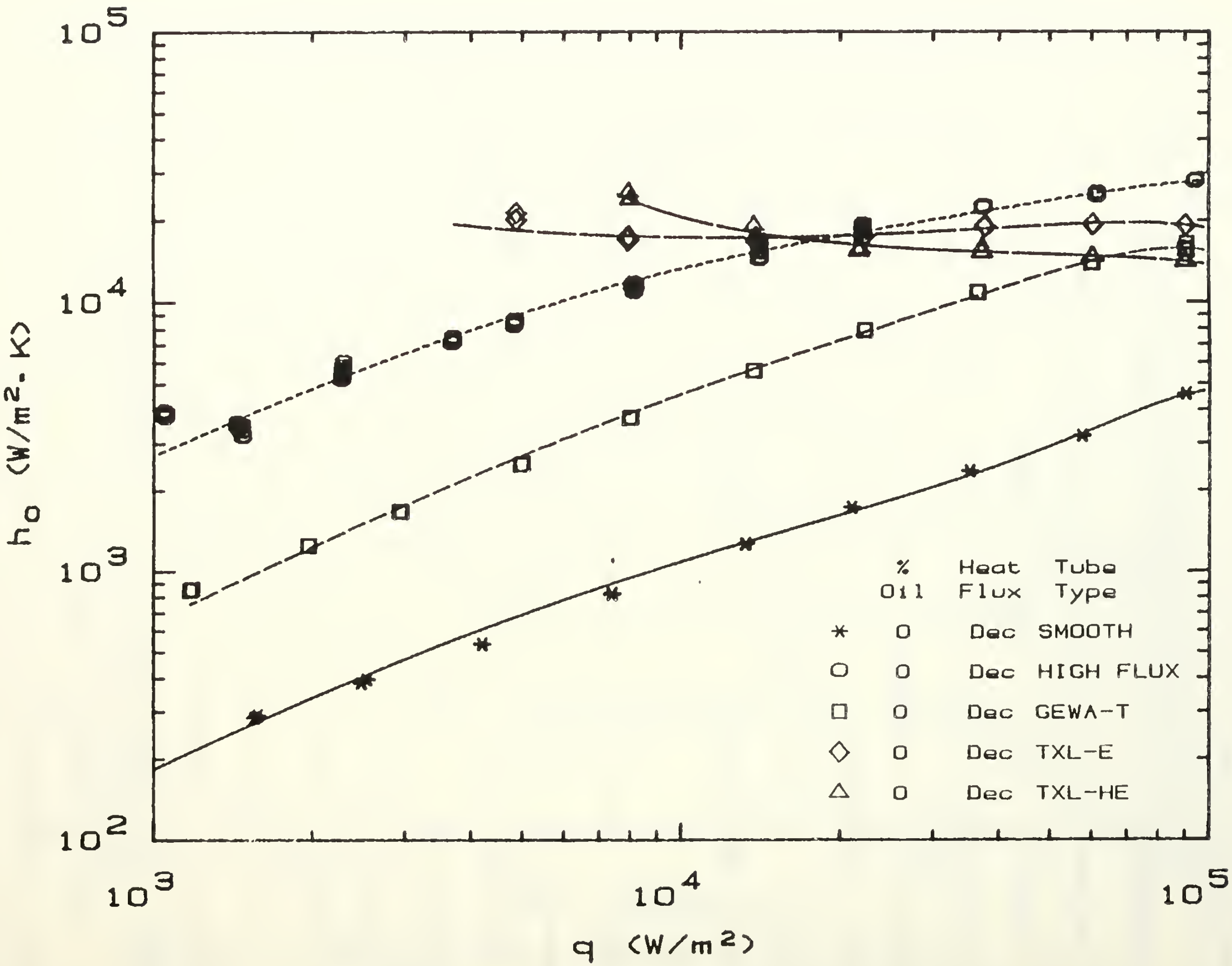


Figure 4.20 Comparison of Boiling Heat-Transfer Coefficients for Smooth, High Flux [Ref. 5] GEWA-T, Thermoexcel-E and Thermoexcel-HE Surfaces in Pure R-114.

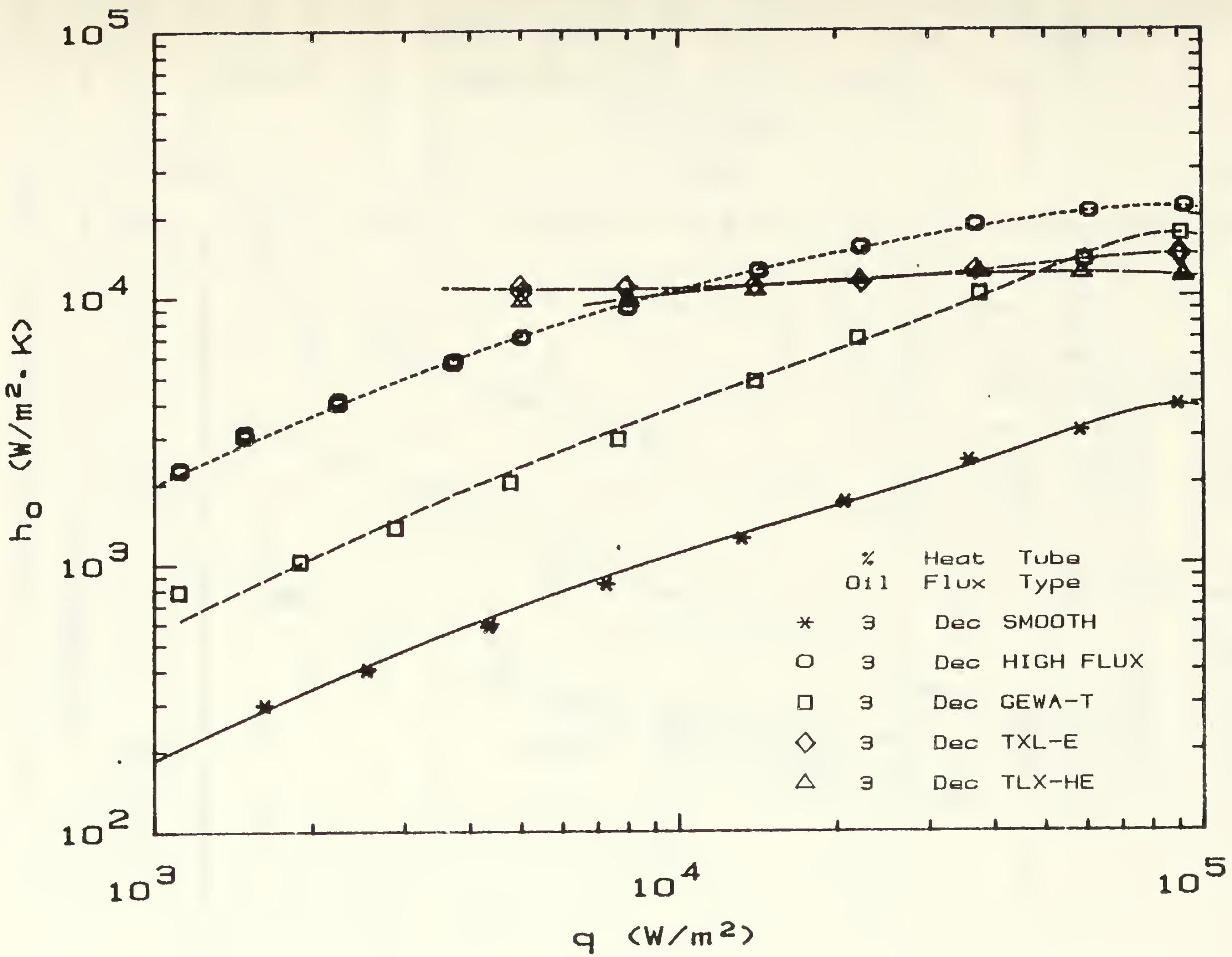


Figure 4.21 Comparison of Boiling Heat-Transfer Coefficients for Smooth, High Flux [Ref. 5] , GEWA-T, Thermoexcel-E and Thermoexcel-HE Surfaces for 3 Percent Oil Content.

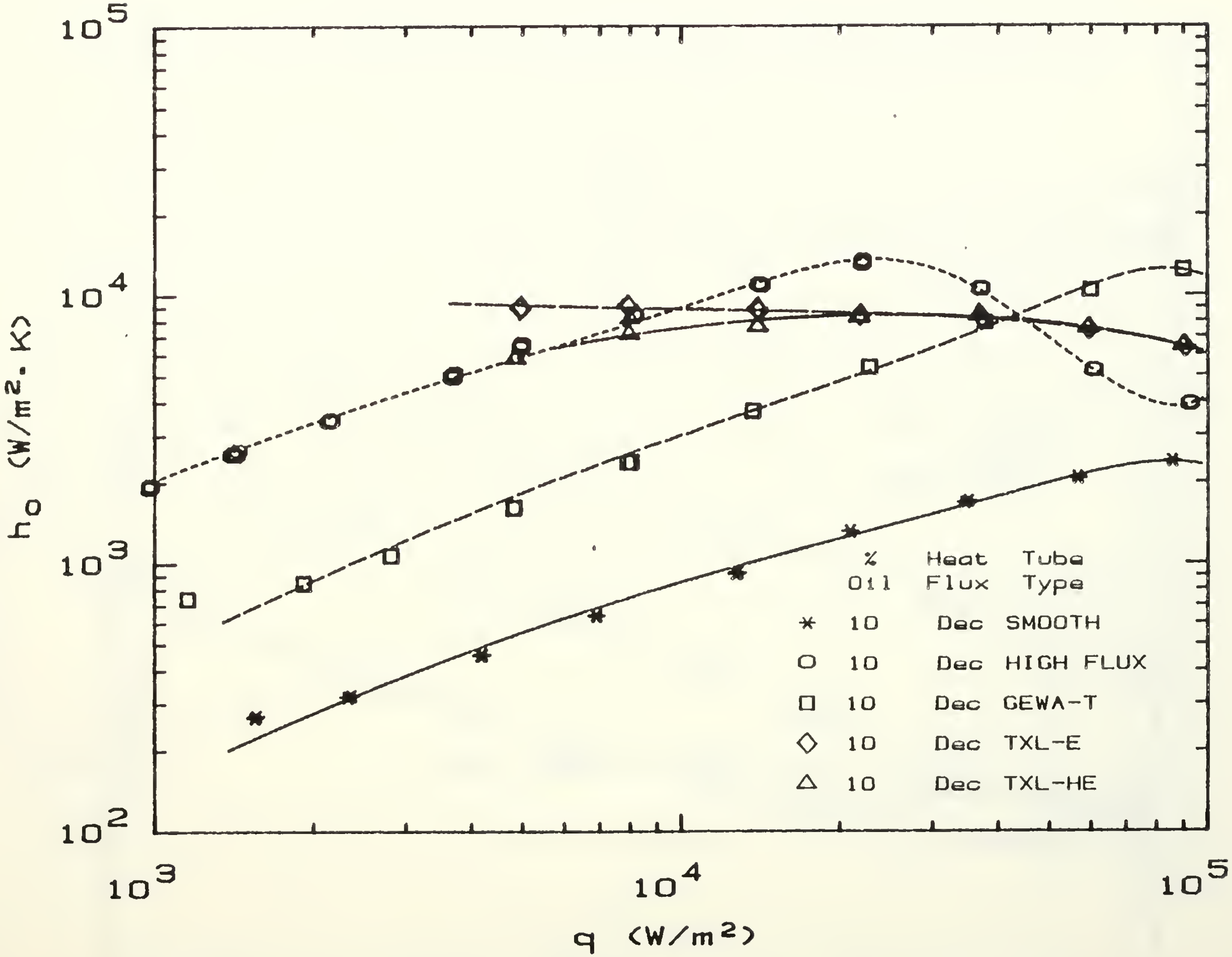


Figure 4.22 Comparison of Boiling Heat-Transfer Coefficients for Smooth, High Flux [Ref. 5] , GEWA-T, Thermoexcel-E and Thermoexcel-HE Surfaces for 10 Percent Oil Content.

tubes with porous coatings or small reentrant cavities is adversely affected by the increase in oil content due to the generation of an oil-rich film in the nucleation sites impeding the tube's performance. This is further evidenced by Figure 4.22, which depicts the performance of all five tubes in R-114-oil mixtures of 10 percent oil. The performance of all the tubes is reduced significantly, while the performance of the High Flux tube is severely decreased in the range of heat-flux settings from 22 kW/m^2 to the maximum setting of 91 kW/m^2. At approximately 45 kW/m^2, the performance of the High Flux tube, the GEWA-T, the Thermoexcel-E and the Thermoexcel-HE tubes are approximately equal, although the performance of the Thermoexcel-E and the Thermoexcel-HE tubes remain nearly constant over the range of heat-flux settings of 14 kW/m^2 to 50 kW/m^2. Although the performance of the High Flux tube exceeds that of the GEWA-T, the Thermoexcel-E and the Thermoexcel-HE tubes over this range, its performance begins to severely degrade at the midpoint of the heat-flux range indicated. In the heat-flux range above 45 kW/m^2, the GEWA-T tube outperformed all the other tubes. This is attributed to the ability of bubbles generated in its larger channels to continually scavenge the oil-rich layer from the tube, and therefore remove the insulating oil from the tube's channels and exterior surface.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. In pure R-114, at a heat flux of 30 kW/m² the pool-boiling heat-transfer coefficient of the Thermoexcel-E, Thermoexcel-HE and GEWA-T tubes were approximately 6.6, 6.1 and 4.2 times, respectively, larger than the baseline smooth tube.

2. In R-114-oil mixtures of 3 percent oil, at a heat flux of 30 kW/m², the pool-boiling heat-transfer coefficient of the Thermoexcel-E, Thermoexcel-HE and GEWA-T tubes were approximately 4.8, 4.6 and 4.0 times, respectively, larger than the smooth tube under the same conditions.

3. In R-114-oil mixtures of 10 percent oil, at a heat flux of 30 kW/m², the performance of the Thermoexcel-E and Thermoexcel-HE tubes were nearly identical, with an enhancement of 4.1 over the pool-boiling heat-transfer coefficient of the smooth tube. The GEWA-T tube, under the same conditions, produced an enhancement of 3.8 over the smooth tube.

4. As oil content in the refrigerant-oil mixture increased, the performance of enhanced surfaces decreased; however, the amount of this decrease was directly related to the size of the subsurface channels (i.e., the larger the reentrant cavity or channel, the less adverse effect of the increased oil content).

5. As the oil content increases in the channels, the greater the adverse effect of the oil-rich layer has on the surface, insulating the surface from the refrigerant and therefore decreasing the performance of the surface.

6. The GEWA-T surface in refrigerant-oil mixtures, with its larger subsurface channels, was able to scavenge the oil-rich layer from its cavities by the bubbling action generated within the channels.

7. The performance of the Thermoexcel-E and Thermoexcel-HE tubes, with their smaller pore size and smaller tunnels, showed significant performance decreases as oil content was increased. The smaller pore and tunnel size under these conditions, were unable to

effectively disperse the oil-rich film from the sub -surface cavities and therefore allowing the oil-rich film to insulate the tube's surface.

B. RECOMMENDATIONS

1. The single-tube testing should be expanded to include multi-tube bundles. This would provide more realistic data with regard to the effects of tubes operating in close proximity to each other.

2. A uniform heat flux is necessary within the boiling tube and within the boiling section itself. Therefore, the present cartridge heaters need to be replaced with more precise heaters, capable of producing a uniform heat flux in the axial direction.

3. The testing of surfaces should be expanded to study the effects of various refrigerant oils.

4. Conduct experiments to establish the physical properties of refrigerant-oil mixtures to enable further understanding into the boiling mechanisms involved.

5. There needs to be additional studies undertaken on the effects of additional boiling temperatures on the mixture properties of the refrigerant-oil mixtures.

APPENDIX A

THERMOCOUPLE CALIBRATION [Ref. 5]

Karasabun [Ref. 17] described the thermocouple calibration procedure in great detail. Reilly [Ref. 5] stated that the data-reduction program utilized differences in thermocouple readings in all computations, such as the amount of the tube wall superheat (Two - Tsat). Reilly stated that the calibration of the thermocouples would be necessary if the thermocouples were measuring quantities such as absolute temperature to determine actual fluid properties. The procedure utilized by Karasabun and Reilly for the initial instrumentation for the experimental apparatus is as contained in Appendix A of Reference 5.

To determine the calibration for the thermocouples, two thermocouples were made, one from the beginning of the wire roll and the second from the end. The seventh-order polynomial equation provided by the wire manufacturer was corrected by adding to it a second-order curve fit of the variation of the manufacturer's computed temperature for a given emf from a known set of reference temperatures as measured by a Hewlett-Packard 2804A quartz thermometer. The thermometer had a temperature resolution of ±0.0001 K and an accuracy of ±0.03 K.

The manufacturer's emf to temperature conversion equation is:

$$T = a_0 + a_1 E + a_2 E^2 + a_3 E^3 + a_4 E^4 + a_5 E^5 + a_6 E^6 + a_7 E^7 \quad (A.1)$$

where

E = thermocouple reading in volts

T = temperature

a_0 = 0.100860910

a_1 = 25727.94369

a_2 = -767345.8295

a_3 = 78025595.81

a_4 = -9247486589

a_5 = 6.97688×10^{11}

a_6 = -2.66192×10^{13}

a_7 = 3.94078×10^{14}

Figure A.1 [Ref. 5] shows the difference in the quartz thermocouple readings and the actual thermocouple readings (discrepancy) plotted as a function of temperature. As can be seen from the figure, the two thermocouples agreed to within 0.05 K of each other. The manufacturer's calibration equation needed an increase of approximately 0.1 K to more accurately convert the emf's to the true temperature. The second-order polynomial correction was as follows;

$$DCP = b_0 + b_1 T + b_2 T^2 \quad (A.2)$$

where

DCP = discrepancy (K)

b_0 = 8.6268968×10^{-2}

b_1 = 3.7619902×10^{-3}

b_2 = $-5.0689259 \times 10^{-5}$

T^2 = thermocouple readings from equation A.1 in C

Therefore, the temperatures computed by the data-reduction program (DRP5) were emf's converted directly to temperatures by equation A.1 and corrected by equation A.2. This calibration was, thus estimated to result in temperature readings within ±0.05 K of the true temperature.

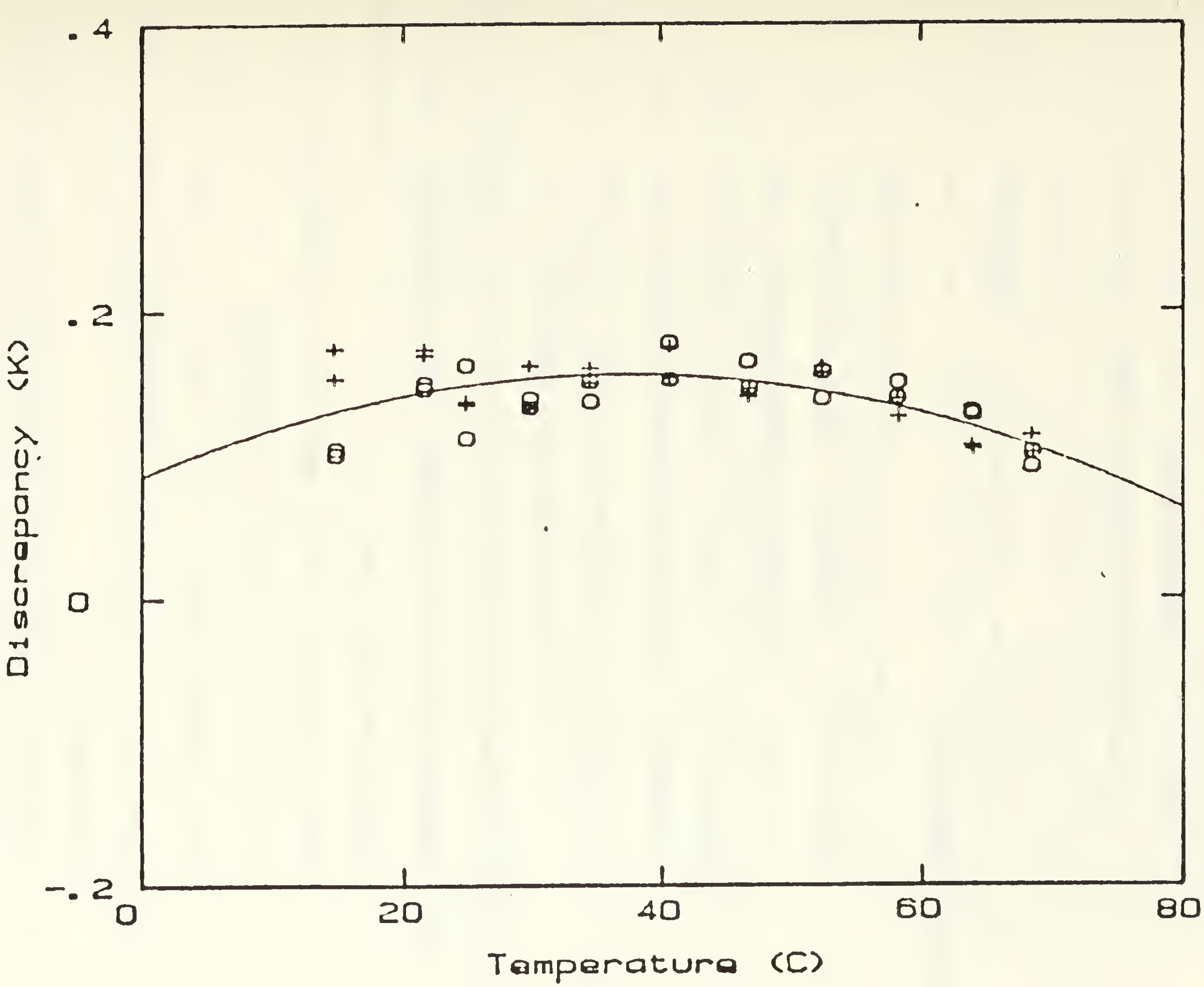


Figure A.1 Thermocouple Discrepancy Correction.

APPENDIX B

DATA-REDUCTION PROGRAM [REF. 5]

The data-reduction program below consists of the following sections:

Main Program	-	Menu of subprogram options
Sub Main	-	Takes or reprocesses data
Sub plot	-	Plots data on log-log scale
Sub Poly	-	Computes least squares curve fit
Sub Plin	-	Plots data on linear-linear scale
Sub Stats	-	Computes average and standard deviation of data

Subprogram Main consists of the following steps:

1. Creates data file for data and plotting file.
2. Annotates tube type.
3. Monitors heat flux or saturation temperature to establish steady-state conditions.
4. Scans HP3497 channels and stores in data file.
5. Converts raw emf's to temperatures, current and voltages.
6. Computes the heat-transfer rate for the tube's internal cartridge heater.
7. Computes the average wall temperature of the tube, the average wall superheat and the film temperature.

8. Computes the physical properties of the R-114 using the given correlation temperature.

9. Computes the natural-convection heat-transfer coefficient of R-114 for the non-boiling tube ends.

10. Computes the heat loss from the non-boiling tube ends.

11. Calculates the corrected heat fluxes from the testing tube to the R-114.

12. Calculates the boiling heat-transfer coefficient of the R-114 from the tube being tested.

13. Prints the data and stores the heat flux and tube wall superheat values in the plot file.

The following is the listing of the complete data-reduction program (DRP5) written in Basic 3.0 for the Hewlett-Packard 9826 computer.

```
1000! FILE NAME: DRP5
1003! DATE:       October 19. 1984
1006! REVISED:    April 25. 1986
1009!
1012  COM /Idp/ Idp
1015  PRINTER IS 1
1018  CALL Select
1021  INPUT "WANT TO SELECT ANOTHER OPTION (1=Y,0=N)?",Isel
1024  IF Isel=1 THEN GOTO 1018
1027  BEEP
1030  BEEP
1033  PRINTER IS 1
1036  PRINT "DATA COLLECTION/REPROCESSING COMPLETED"
1039  END
1042  SUB Main
1045  COM /Idp/ Idp
1048  COM /Cc/ C(7).Ical
1051  COM /Wil/ D2.Di.Do.L.Lu.Kcu
1054  DIM Emf(12),T(12),D1a(11).D2a(11).Dia(11).Doa(11).La(11),Lua(11),Kcua(11),
Et(19),Tn$(4)[15]
1057  DATA 0.10086091.25727.94369.-767345.8295.78025595.81
1060  DATA -9247486589.6.97688E+11,-2.66192E+13,3.94078E+14
1063  READ C(*)
1066! DATA "Smooth","High Flux","Thermoexel-E","Thermoexel-HE"
1069  DATA Smooth,High Flux,Turbo-B,High Flux Mod,Turbo-B Mod
1072  READ Tn$(*)
1075  PRINTER IS 701
1078  BEEP
1081  IF Idp=4 THEN PRINTER IS 1
1084  IF Idp=4 THEN GOTO 1774
1087  INPUT "ENTER MONTH. DATE AND TIME (MM:DD:HH:MM:SS)",Date$
1090  OUTPUT 709:"TD":Date$
1093  OUTPUT 709:"TD"
1096  ENTER 709;Date$
1099  PRINT
1102  PRINT "            Month. date and time :";Date$
1105  PRINT
1108  PRINT USING "10X,""NOTE: Program name : DRP4"""
1111  BEEP
1114  INPUT "ENTER DISK NUMBER",Dn
1117  PRINT USING "16X,""Disk number   = "",ZZ";Dn
1120  BEEP
1123  INPUT "ENTER INPUT MODE (0=3054A,1=FILE)",Im
1126  BEEP
1129  INPUT "SELECT HEATING MODE (0=ELEC: 1=WATER)",Ihm
1132  BEEP
1135  INPUT "ENTER THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
1138  IF Im=0 THEN
1141  BEEP
1144  INPUT "GIVE A NAME FOR THE RAW DATA FILE",D2_file$
1147  PRINT USING "16X,""New file name: "",14A";D2_file$
1150  Size1=20
1153  CREATE BDAT D2_file$,Size1
1156  ASSIGN @File2 TO D2_file$
1159!
1162! DUMMY FILE UNTIL Nrun KNOWN
1165  D1_file$="DUMMY"
1168  CREATE BDAT D1_file$,Size1
1171  ASSIGN @File1 TO D1_file$
1174  OUTPUT @File1;Date$
```

```
1177  IF Ihm=0 THEN
1180  BEEP
1183  INPUT "ENTER NUMBER OF DEFECTIVE TCS (0=DEFAULT)",Idtc
1186  IF Idtc=0 THEN
1189  Ldtc1=0
1192  Ldtc2=0
1195  PRINT USING "16X,""No defective TCs exist"""
1198  END IF
1201  IF Idtc=1 THEN
1204  BEEP
1207  INPUT "ENTER DEFECTIVE TC LOCATION",Ldtc1
1210  PRINT USING "16X,""TC is defective at location "",D";Ldtc1
1213  Ldtc2=0
1216  END IF
1219  IF Idtc=2 THEN
1222  BEEP
1225  INPUT "ENTER DEFECTIVE TC LOCATIONS",Ldtc1,Ldtc2
1228  PRINT USING "16X,""TC are defective at locations "",D,4X,D";Ldtc1,Ldtc2
1231  END IF
1234  IF Idtc>2 THEN
1237  BEEP
1240  PRINTER IS 1
1243  BEEP
1246  PRINT "INVALID ENTRY"
1249  PRINTER IS 701
1252  GOTO 1180
1255  END IF
1258  END IF
1261  OUTPUT @File1;Ldtc1,Ldtc2
1264! Im=1 option
1267  ELSE
1270  BEEP
1273  INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D2_file$
1276  PRINT USING "16X,""Old file name: "",14A";D2_file$
1279  ASSIGN @File2 TO D2_file$
1282  ENTER @File2;Nrun
1285  ENTER @File2;Dold$
1288  PRINT USING "16X,""This data set taken on : "",14A";Dold$
1291  ENTER @File2;Ldtc1,Ldtc2
1294  IF Ldtc1>0 OR Ldtc2>0 THEN
1297  PRINT USING "16X,""Thermocouples were defective at locations:"",2(3D,4X)";
Ldtc1,Ldtc2
1300  END IF
1303  ENTER @File2;Itt
1306  END IF
1309! IF Im=0 AND Ihm=1 THEN 1595
1312  BEEP
1315  INPUT "WANT TO CREATE A PLOT FILE? (0=N,1=Y)",Iplot
1318  IF Iplot=1 THEN
1321  BEEP
1324  INPUT "GIVE NAME FOR PLOT FILE",P_file$
1327  CREATE BDAT P_file$,4
1330  ASSIGN @Plot TO P_file$
1333  END IF
1336  IF Ihm=1 THEN
1339  BEEP
1342  INPUT "WANT TO CREATE Uo FILE? (0=N,1=Y)",Iuf
1345  IF Iuf=1 THEN
1348  BEEP
1351  INPUT "ENTER Uo FILE NAME",Ufile$
```

```
1354  CREATE BDAT Ufile$,4
1357  ASSIGN @Ufile TO Ufile$
1360  END IF
1363  BEEP
1366  INPUT "WANT TO CREATE Re FILE? (0=N,1=Y)",Ire
1369  IF Ire=1 THEN
1372  BEEP
1375  INPUT "ENTER Re FILE NAME",Refile$
1378  CREATE BDAT Refile$,10
1381  ASSIGN @Refile TO Refile$
1384  END IF
1387  END IF
1390  PRINTER IS 1
1393  IF Im=0 THEN
1396  BEEP
1399  PRINT USING "4X,""Select tube number"""
1402  IF Ihm=0 THEN
1405  PRINT USING "6X,""0  Smooth 4 inch Ref"""
1408  PRINT USING "6X,""1  Smooth 4 inch Cu (Press/Slide)"""
1411  PRINT USING "6X,""2  Soft Solder 4 inch Cu"""
1414  PRINT USING "6X,""3  Soft Solder 4 inch HIGH FLUX"""
1417  PRINT USING "6X,""4  Wieland Hard 8 inch"""
1420  PRINT USING "6X,""5  HIGH FLUX 8 inch"""
1423  PRINT USING "6X,""6  GEWA-K 19 Fins/in"""
1426  PRINT USING "6X,""7  GEWA-K 26 Fins/in"""
1429  PRINT USING "6X,""8  GEWA-T 19 Fins/in"""
1432  PRINT USING "6X,""9  GEWA-T 26 Fins/in"""
1435  PRINT USING "6X,""10 THERMOEXCEL-E"""
1438  PRINT USING "6X,""11 THERMOEXCEL-HE"""
1441  ELSE
1444  PRINT USING "6X,""0  Smooth tube"""
1447  PRINT USING "6X,""1  High Flux"""
1450  PRINT USING "6X,""2  Turbo-B"""
1453  PRINT USING "6X,""3  High Flux Mod"""
1456  PRINT USING "6X,""4  Turbo-B Mod"""
1459  END IF
1462  INPUT Itt
1465  OUTPUT @File1;Itt
1468  END IF
1471  PRINTER IS 701
1474  IF Itt<10 THEN PRINT USING "16X,""Tube Number:    "",D":Itt
1477  IF Itt>9 THEN PRINT USING "16X,""Tube Number:    "",DD":Itt
1480  IF Ihm=1 THEN PRINT USING "16X,""Tube Type:      "",15A":Tn$(Itt)
1483  BEEP
1486  INPUT "ENTER OUTPUT VERSION (0=LONG,1=SHORT,2=NONE)",Iov
1489  BEEP
1492  INPUT "SELECT (0=LIQ,1=VAP,2=(LIQ+VAP)/2)",Ilqv
1495!
1498! DIMENSIONS FO TESTED TUBES
1501! ELECTRIC HEATED MODE
1504! D1=Diameter at thermocouple positions
1507  DATA .0111125,.0111125,.0111125,.0129540,.012446,.0129540,.0100965
1510  DATA .0100965,.01157,.01157,.01157,.01157
1513  READ D1a(*)
1516  D1=D1a(Itt)
1519!
1522! D2=Diameter of test section to the base of fins
1525  DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270
1528  DATA .0127,.0138,.0138,.0138,.0138
1531  READ D2a(*)
```

```
1534!
1537! Di=Inside diameter of unenhanced ends
1540  DATA .0127,.0127,.0127,.0132,.0127,.0132,.0111125,.0111125,.0118,.0118,.01
18,.0118
1543  READ Dia(*)
1546!
1549! Do=Outside diameter of unenhanced ends
1552  DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270,.01270,.01331,
.01331,.01331,.01331
1555  READ Doa(*)
1558!
1561! L=Length of enhanced surface
1564  DATA .1016,.1016,.1016,.1016,.2032,.2032,.2032,.2032,.2032,.2032,.2032,.20
32
1567  READ La(*)
1570!
1573! Lu=Length of unenhanced surface at the ends
1576  DATA .0254,.0254,.0254,.0254,.0762,.0762,.0762,.0762,.0762,.0762,.0762,.07
62
1579  READ Lua(*)
1582!
1585! Kcu=Thermal Conductivity of tube
1588  DATA 398,344,344.45,344,45,344,944,398,398,398,398
1591  READ Kcua(*)
1594  IF Ihm=1 THEN
1597!
1600! Data statements for water heating mode
1603!
1606  DATA 0.015875,0.015875,0.0169,0.0138,0.0169,0.0,0,0,0
1609  READ D2a(*)
1612  DATA 0.0127,0.0127,0.0145,0.0127,0.0145,0,0,0,0,0
1615  READ Dia(*)
1618  DATA 0.015875,0.015875,0.0169,0.015875,0.0169,0,0,0,0,0
1621  READ Doa(*)
1624  DATA 0.3048,0.3048,0.3048,0.3048,0.3048,0,0,0,0,0
1627  READ La(*)
1630  DATA 0.0254,0.0254,0.0254,0.0254,0.0254,0,0,0,0,0
1633  READ Lua(*)
1636  DATA 398.45,398,45,398.0,0,0,0,0
1639  READ Kcua(*)
1642  END IF
1645  D2=D2a(Itt)
1648  Di=Dia(Itt)
1651  Do=Doa(Itt)
1654  L=La(Itt)
1657  Lu=Lua(Itt)
1660  Kcu=Kcua(Itt)
1663  Xn=.8
1666  Fr=.3
1669  IF Itt=0 THEN Cf=1.70E+9
1672  IF Itt>0 THEN Cf=3.7037E+10
1675  A=PI*(Do^2-Di^2)/4
1678  P=PI*Do
1681  IF Ihm=1 THEN
1684  BEEP
1687  INPUT "TUBE INITIATION MODE. (1=HOT WATER.2=STEAM,3=COLD WATER)",Itim
1690  IF Itim=1 THEN PRINT USING "16X.""Tube Initiate: Hot Water"""
1693  IF Itim=2 THEN PRINT USING "16X.""Tube Initiate: Steam"""
1696  IF Itim=3 THEN PRINT USING "16X.""Tube Initiate: Cold Water"""
1699  INPUT "TEMP/VEL MODE: (0=T-CONST.V-DEC:1=T-DEC,V-CONST; 2=T-INC,V-CONST)",
Itv
```

```
1702  IF Itv=0 THEN PRINT USING "16X,""Temp/Vel Mode: Constant/Decreasing"""
1705  IF Itv=1 THEN PRINT USING "16X,""Temp/Vel Mode: Decreasing/Constant"""
1708  IF Itv=2 THEN PRINT USING "16X,""Temp/Vel Mode: Increasing/Constant"""
1711  INPUT "WANT TO RUN WILSON PLOT? (1=Y,0=N)",Iwil
1714  IF Ihm=1 AND Iwil=0 THEN
1717  IF Itt=0 THEN Ci=.032
1720  IF Itt=1 OR Itt=3 THEN Ci=.059
1723  IF Itt=2 OR Itt=4 THEN Ci=.062
1726  BEEP
1729  INPUT "ENTER CI (DEF: WH=.032,HF=.059,TB=.062)",Ci
1732  PRINT USING "16X,""Sieder-Tate """
1735  PRINT USING "16X,""  Constant   = "",Z.4D";Ci
1738  END IF
1741  END IF
1744  IF Ihm=1 AND Im=1 AND Iwil=1 THEN
1747  IF Itt=0 THEN Ci=.032
1750  IF Itt=1 OR Itt=3 THEN Ci=.059
1753  IF Itt=2 OR Itt=4 THEN Ci=.062
1756  ASSIGN @File2 TO *
1759  CALL Wilson(Cf,Ci)
1762  ASSIGN @File2 TO D2_file$
1765  ENTER @File2;Nrun,Dold$,Ldtc1,Ldtc2,Itt
1768  END IF
1771  Nsub=0
1774  IF Idp=4 THEN Ihm=1
1777  IF Ihm=1 THEN Nsub=8
1780  Ntc=6
1783  IF Ihm=0 THEN Ntc=12
1786  J=1
1789  Sx=0
1792  Sy=0
1795  Sxs=0
1798  Sxy=0
1801 Repeat: !
1804  IF Im=0 THEN
1807  Dtld=2.22
1810  Ido=2
1813  ON KEY 0,15 RECOVER 1801
1816  PRINTER IS 1
1819  PRINT USING "4X,""SELECT OPTION"""
1822  PRINT USING "6X,""0=TAKE DATA"""
1825  IF Ihm=0 THEN PRINT USING "6X,""1=SET HEAT FLUX"""
1828  IF Ihm=1 THEN PRINT USING "6X,""1=SET WATER FLOW RATE"""
1831  PRINT USING "6X,""2=SET Tsat"""
1834  PRINT USING "4X,""NOTE: KEY 0 = ESCAPE"""
1837  BEEP
1840  INPUT Ido
1843  IF Ido>2 THEN Ido=2
1846  IF Ido=0 THEN 2296
1849!
1852! LOOP TO SET HEAT FLUX OR FLOWMETER SETTING
1855  IF Ido=1 THEN
1858  IF Ihm=0 THEN
1861  OUTPUT 709;"AR AF12 AL13 VR5"
1864  BEEP
1867  INPUT "ENTER DESIRED Qdp",Dqdp
1870  PRINT USING "4X,""DESIRED Qdp  ACTUAL Qdp"""
1873  Err=1000
1876  FOR I=1 TO 2
1879  OUTPUT 709;"AS SA"
```

```
1882  Sum=0
1885  FOR Ji=1 TO 5
1888  ENTER 709:E
1891  Sum=Sum+E
1894  NEXT Ji
1897  IF I=1 THEN Volt=Sum*5
1900  IF I=2 THEN Amp=E
1903  NEXT I
1906  Aqdp=Volt*Amp/(PI*D2*L)
1909  IF ABS(Aqdp-Dqdp)>Err THEN
1912  IF Aqdp>Dqdp THEN
1915  BEEP 4000,.2
1918  BEEP 4000,.2
1921  BEEP 4000,.2
1924  ELSE
1927  BEEP 250,.2
1930  BEEP 250,.2
1933  BEEP 250,.2
1936  END IF
1939  PRINT USING "4X,MZ.3DE,2X,MZ.3DE":Dqdp,Aqdp
1942  WAIT 2
1945  GOTO 1876
1948  ELSE
1951  BEEP
1954  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Dqdp,Aqdp
1957  Err=500
1960  WAIT 2
1963  GOTO 1876
1966  END IF
1969  ELSE
1972  BEEP
1975  INPUT "ENTER FLOWMETER SETTING",Fms
1978  GOTO 1819
1981  END IF
1984  END IF
1987!
1990! LOOP TO SET Tsat
1993  IF Ido=2 THEN
1996  IF Ikdt=1 THEN 2011
1999  BEEP
2002  INPUT "ENTER DESIRED Tsat",Dtld
2005! PRINT USING "4X,"" DTsat  ATsat   Rate    Tv     Rate"""
2008  Ikdt=1
2011  Old1=0
2014  Old2=0
2017  Nn=1
2020  Nrs=Nn MOD 15
2023  Nn=Nn+1
2026  IF Nrs=1 THEN
2029  PRINT USING "4X,""  Tsat    Tld1    Tld2     Tv    Tsump   Tinlet    Tpile
     Tout"""
2032  END IF
2035  IF Ihm=0 THEN OUTPUT 709:"AR AF8 AL11 VR5"
2038  IF Ihm=1 THEN OUTPUT 709:"AR AF0 AL5 VR5"
2041  FOR I=1 TO 6
2044  IF Ihm=0 AND I>4 THEN 2125
2047  Sum=0
2050  OUTPUT 709:"AS SA"
2053  FOR Ji=1 TO 20
2056  ENTER 709:Eliq
```

```
2059  Sum=Sum+Eliq
2062  NEXT Ji
2065  Eliq=Sum/20
2068  Tld=FNTvsv(Eliq)
2071  IF I=1 THEN Tld1=Tld
2074  IF I=2 THEN Tld2=Tld
2077  IF I=3 THEN Tv=Tld
2080  IF I=4 THEN Tsump=Tld
2083  IF I=5 THEN Tinlet=Tld
2086  IF I=6 THEN Tout=Tld
2089  NEXT I
2092  IF Ihm=1 THEN
2095  OUTPUT 709:"AR AF20 AL20 VR5"
2098  OUTPUT 709:"AS SA"
2101  Sum=0
2104  FOR Kk=1 TO 20
2107  ENTER 709:E
2110  Sum=Sum+E
2113  NEXT Kk
2116  Emf(7)=ABS(Sum/20)
2119  Tpile=Emf(7)/3.96E-4
2122  END IF
2125  Atld=(Tld1+Tld2)*.5
2128  IF ABS(Atld-Dtld)>.2 THEN
2131  IF Atld>Dtld THEN
2134  BEEP 4000,.2
2137  BEEP 4000,.2
2140  BEEP 4000,.2
2143  ELSE
2146  BEEP 250,.2
2149  BEEP 250,.2
2152  BEEP 250,.2
2155  END IF
2158  Err1=Atld-Old1
2161  Old1=Atld
2164  Err2=Tv-Old2
2167  Old2=Tv
2170  IF Ihm=0 THEN PRINT USING "4X,5(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
2173  IF Ihm=1 AND Idp=0 THEN PRINT USING "4X,7(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Ts
ump,Tinlet,Tpile
2176* IF Ihm=1 AND Idp=4 THEN PRINT USING "4X,5(MDD.DD,2X),3(M3D.DD,2X)";Dtld,Tl
d1,Tld2,Tv,Tsump,Tin
2179  WAIT 2
2182  GOTO 2020
2185  ELSE
2188  IF ABS(Atld-Dtld)>.1 THEN
2191  IF Atld>Dtld THEN
2194  BEEP 3000,.2
2197  BEEP 3000,.2
2200  ELSE
2203  BEEP 800,.2
2206  BEEP 800,.2
2209  END IF
2212  Err1=Atld-Old1
2215  Old1=Atld
2218  Err2=Tv-Old2
2221  Old2=Tv
2224  IF Ihm=0 THEN PRINT USING "4X,5(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
2227* IF Ihm=1 THEN PRINT USING "4X,5(MDD.DD,2X),3(M3D.DD,1X)";Dtld,Tld1,Tld2,Tv
,Tsump,Tinlet,Tpile,
```

```
2230  WAIT 2
2233  GOTO 2020
2236  ELSE
2239  BEEP
2242  Err1=Atld-Old1
2245  Old1=Atld
2248  Err2=Tv-Old2
2251  Old2=Tv
2254  IF Ihm=0 THEN PRINT USING "4X,5(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
2257  IF Ihm=1 THEN PRINT USING "4X,8(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump,Tinlet
,Tpile,Tout
2260  WAIT 2
2263  GOTO 2020
2266  END IF
2269  END IF
2272  END IF
2275! ERROR TRAP FOR Ido OUT OF BOUNDS
2278  IF Ido>2 THEN
2281  BEEP
2284  GOTO 1819
2287  END IF
2290!
2293! TAKE DATA IF Im=0 LOOP
2296  IF Ikol=1 THEN 2308
2299  BEEP
2302  INPUT "ENTER BULK OIL %",Bop
2305  Ikol=1
2308  IF Ihm=0 THEN OUTPUT 709:"AR AF0 AL11 VRS"
2311  IF Ihm=1 THEN OUTPUT 709:"AR AF0 AL5 VRS"
2314  IF Ihm=0 THEN Ntc=12
2317  FOR I=1 TO Ntc
2320  OUTPUT 709:"AS SA"
2323  Sum=0
2326  FOR Ji=1 TO 20
2329  ENTER 709:E
2332  Sum=Sum+E
2335  IF I=(9-Nsub) OR I=(10-Nsub) THEN Et(Ji-1)=E
2338  NEXT Ji
2341  Kdl=0
2344  IF I=(9-Nsub) OR I=(10-Nsub) THEN
2347  Eave=Sum/20
2350  Sum=0.
2353  FOR Jk=0 TO 19
2356  IF ABS(Et(Jk)-Eave)<5.0E-6 THEN
2359  Sum=Sum+Et(Jk)
2362  ELSE
2365  Kdl=Kdl+1
2368  END IF
2371  NEXT Jk
2374  IF I=(9-Nsub) OR I=(10-Nsub) THEN PRINT USING "4X,""Kdl = "",DD";Kdl
2377  IF Kdl>10 THEN
2380  BEEP
2383  BEEP
2386  PRINT USING "4X,""Too much scattering in data - repeat data set"""
2389  GOTO 1816
2392  END IF
2395  END IF
2398  Emf(I)=Sum/(20-Kdl)
2401  NEXT I
2404  IF Ihm=1 THEN
2407  OUTPUT 709:"AR AF20 AL20 VRS"
```

```
2590  NEXT I
2593  Tw=Twa/(8-Idtc)
2596  END IF
2599  Tld=T(9-Nsub)
2602  Tld2=T(10-Nsub)
2605  Tlda=(Tld+Tld2)*.5
2608  Tv=T(11-Nsub)
2611  IF Itt<3 AND Ihm=0 THEN
2614  Tld2=-99.99
2617  Tv=(T(10)+T(11))/2
2620  END IF
2623  Tsump=T(12-Nsub)
2626  IF Ihm=0 THEN 2635
2629  Tinlet=T(13-Nsub)
2632  Tout=T(14-Nsub)
2635  IF Ihm=0 THEN
2638  Amp=ABS(Ir)
2641  Volt=ABS(Vr)*25
2644  Q=Volt*Amp
2647  END IF
2650  IF Itt=0 AND Ihm=0 THEN
2653  Kcu=FNKcu(Tw)
2656  ELSE
2659  Kcu=Kcua(Itt)
2662  END IF
2665!
2668! FOURIER CONDUCTION EQUATION WITH CONTACT RESISTANCE NEGLECTED
2671  IF Ihm=0 THEN Tw=Tw-Q*LOG(D2/D1)/(2*PI*Kcu*L)
2674  IF Ilqv=0 THEN Tsat=Tlda
2677  IF Ilqv=1 THEN Tsat=(Tlda+Tv)*.5
2680  IF Ilqv=2 THEN Tsat=Tv
2683  IF Ihm=1 THEN
2686  Tavg=Tinlet
2689  Grad=37.9853+.104388*Tavg
2692  Tdrop=ABS(Emf(7))*1.E+6/(10*Grad)
2695  Tavgc=Tinlet-Tdrop*.5
2698  IF ABS(Tavg-Tavgc)>.01 THEN
2701  Tavg=(Tavg+Tavgc)*.5
2704  GOTO 2689
2707  END IF
2710!
2713! COMPUTE WATER PROPERTIES
2716  IF Ihm=1 THEN
2719  Kw=FNKw(Tavg)
2722  Muwa=FNMuw(Tavg)
2725  Cpw=FNCpw(Tavg)
2728  Prw=FNPrw(Tavg)
2731  Rhow=FNRhow(Tavg)
2734  Twi=Tavg
2737!
2740! Compute MDOT
2743  Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
2746! Mdot=Mdot*(1.0365-Tinlet*(1.96644E-3-Tinlet*5.252E-6))/1.0037
2749  Kdt=0
2752  Q=Mdot*Cpw*Tdrop
2755  Lmtd=Tdrop/LOG((Tinlet-Tsat)/(Tinlet-Tdrop-Tsat))
2758  Uo=Q/(PI*Do*L*Lmtd)
2761  Rw=Do*LOG(Do/Di)/(2.*Kcu)
2764  Tw=Tsat+Fr*Lmtd
```

```
2410  OUTPUT 709;"AS SA"
2413  Sum=0
2416  FOR Kk=1 TO 20
2419  ENTER 709;E
2422  Sum=Sum+E
2425  NEXT Kk
2428  Emf(7)=ABS(Sum)/20
2431  END IF
2434  IF Ihm=0 THEN
2437  OUTPUT 709;"AR AF12 AL13 VR5"
2440  FOR I=1 TO 2
2443  OUTPUT 709;"AS SA"
2446  Sum=0
2449  FOR Ji=1 TO 2
2452  ENTER 709;E
2455  Sum=Sum+E
2458  NEXT Ji
2461  IF I=1 THEN Vr=Sum/2
2464  IF I=2 THEN Ir=Sum/2
2467  NEXT I
2470  END IF
2473  ELSE
2476  IF Ihm=0 THEN ENTER @File2;Bop,Told$,Emf(*),Vr,Ir
2479  IF Ihm=1 THEN ENTER @File2;Bop,Told$,Emf(*),Fms
2482  END IF
2485!
2488! CONVERT emf'S TO TEMP,VOLT,CURRENT
2491  Twa=0
2494  FOR I=1 TO Ntc
2497  IF Idtc>0 THEN
2500  IF I=Ldtc1 OR I=Ldtc2 THEN
2503  T(I)=-99.99
2506  GOTO 2536
2509  END IF
2512  END IF
2515  IF Itt<4 AND Ihm=0 THEN
2518  IF I>4 AND I<9 THEN
2521  T(I)=-99.99
2524  GOTO 2536
2527  END IF
2530  END IF
2533  T(I)=FNTvsv(Emf(I))
2536  NEXT I
2539  IF Itt<4 THEN
2542  FOR I=1 TO 4
2545  IF I=Ldtc1 OR I=Ldtc2 THEN
2548  Twa=Twa
2551  ELSE
2554  Twa=Twa+T(I)
2557  END IF
2560  NEXT I
2563  Twa=Twa/(4-Idtc)
2566  ELSE
2569  IF Ihm=1 THEN 2599
2572  FOR I=1 TO 8
2575  IF I=Ldtc1 OR I=Ldtc2 THEN
2578  Twa=Twa
2581  ELSE
2584  Twa=Twa+T(I)
2587  END IF
```

```
2767  Vw=Mdot/(Rhow*PI*Di^2/4)
2770  Rew=Rhow*Vw*Di/Muwa
2773  Hi=Ci*Kw/Di*Rew^.8*Prw^(1/3.)*(Muwa/FNMuw(Twi))^.14
2776  Twic=Tavg-Q/(PI*Do*L*Hi)
2779  IF ABS(Twi-Twic)>.01 THEN
2782  Twi=(Twi+Twic)*.5
2785  GOTO 2773
2788  END IF
2791  Twi=(Twi+Twic)*.5
2794  Ho=1/(1/Uo-Do/(Di*Hi)-Rw)
2797  END IF
2800  END IF
2803  IF Ihm=1 THEN
2806  Thetab=Q/(Ho*PI*Do*L)
2809  Tw=Tsat+Thetab
2812  ELSE
2815  Thetab=Tw-Tsat
2818  END IF
2821  IF Thetab<0 THEN
2824  BEEP
2827  INPUT "TWALL<TSAT (0=CONTINUE. 1=END)",Iev
2830  IF Iev=0 THEN GOTO 1804
2833  IF Iev=1 THEN 3130
2836  END IF
2839!
2842! COMPUTE VARIOUS PROPERTIES
2845  Tfilm=(Tw+Tsat)*.5
2848  Rho=FNRho(Tfilm)
2851  Mu=FNMu(Tfilm)
2854  K=FNK(Tfilm)
2857  Cp=FNCp(Tfilm)
2860  Beta=FNBeta(Tfilm)
2863  Hfg=FNHfg(Tsat)
2866  Ni=Mu/Rho
2869  Alpha=K/(Rho*Cp)
2872  Pr=Ni/Alpha
2875  Psat=FNPsat(Tsat)
2878!
2881! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
2884! FOR UNENHANCED END(S)
2887  Hbar=190
2890  Fe=(Hbar*P/(Kcu*A))^.5*Lu
2893  Tanh=FNTanh(Fe)
2896  Theta=Thetab*Tanh/Fe
2899  Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni*Alpha))^.166667
2902  Yy=(1+(.559/Pr)^(9/16))^(8/27)
2905  Hbarc=K/Do*(.6+.387*Xx/Yy)^2
2908  IF ABS((Hbar-Hbarc)/Hbarc)>.001 THEN
2911  Hbar=(Hbar+Hbarc)*.5
2914  GOTO 2890
2917  END IF
2920!
2923! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED END(S)
2926  Q1=(Hbar*P*Kcu*A)^.5*Thetab*Tanh
2929  Qc=Q-2*Q1
2932  As=PI*D2*L
2935!
2938! COMPUTE ACTUAL HEAT FLUX AND BOILING COEFFICIENT
2941  Qdp=Qc/As
2944  Htube=Qdp/Thetab
```

```
2947  Csf=(Cp*Thetab/Hfg)/(Qdp/(Mu*Hfg)*(.014/(9.81*Rho)^.5)^(1/3.)*Pr^1.7)
2950!
2953! RECORD TIME OF DATA TAKING
2956  IF Im=0 THEN
2959  OUTPUT 709;"TD"
2962  ENTER 709:Told$
2965  END IF
2968!
2971! OUTPUT DATA TO PRINTER
2974  PRINTER IS 701
2977  IF Iov=0 THEN
2980  PRINT
2983  PRINT USING "10X,""Data Set Number = "",DDD,2X,""Bulk Oil % = "",DD.D,5X,1
4A";J,Bop,Told$
2986  IF Ihm=0 THEN
2989  PRINT USING "10X,""TC No:    1       2       3       4       5       6       7
    8"""
2992  PRINT USING "10X,""Temp :"",8(1X,MDD.DD)";T(1),T(2),T(3),T(4),T(5),T(6),T(
7),T(8)
2995  PRINT USING "10X,"" Twa    Tliqd   Tliqd2  Tvapr  Psat   Tsump"""
2998  PRINT USING "10X,2(MDD.DD,1X),1X,MDD.DD,1X,2(1X,MDD.DD),2X,MDD.D";Tw,Tld,T
ld2,Tv,Psat,Tsump
3001  PRINT USING "10X,"" Thetab  Htube       Qdp"""
3004  PRINT USING "10X,MDD.3D,1X,MZ.3DE,1X,MZ.3DE";Thetab,Htube,Qdp
3007  ELSE
3010  PRINT USING "10X,"" Fms    Vw    Tsat   Tinl Tdrop Thetab      q           Uo
   Ho"""
3013* PRINT USING "10X,4(2D.DD,1X),Z.3D,1X,DD.DD,1X,3(MZ.3DE,1X)";Fms,Vw,Tsat,Ti
nlet,Tdrop,Thetab,Qd
3016  END IF
3019  END IF
3022  IF Iov=1 THEN
3025  IF J=1 THEN
3028  PRINT
3031  IF Ihm=0 THEN
3034  PRINT USING "10X,"" RUN No  Oil%  Tsat    Htube      Qdp        Thetab"""
3037  ELSE
3040  PRINT USING "10X,""  FMS    OIL%  TSAT    HTUBE      QDP        THETAB"""
3043  END IF
3046  END IF
3049  IF Ihm=0 THEN
3052  PRINT USING "12X,3D,4X,DD,2X,MDD.DD,3(1X,MZ.3DE)";J,Bop,Tsat,Htube,Qdp,The
tab
3055  ELSE
3058  PRINT USING "12X,3D,4X,DD,2X,MDD.DD,3(1X,MZ.3DE)";Fms,Bop,Tsat,Htube,Qdp,T
hetab
3061  END IF
3064  END IF
3067  IF Im=0 THEN
3070  BEEP
3073  INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",Ok
3076  END IF
3079  IF Ok=1 OR Im=1 THEN J=J+1
3082  IF Ok=1 AND Im=0 THEN
3085  IF Ihm=0 THEN OUTPUT @File1;Bop,Told$,Emf(*),Vr,Ir
3088  IF Ihm=1 THEN OUTPUT @File1;Bop,Told$,Emf(*),Fms
3091  END IF
3094  IF Iuf=1 THEN OUTPUT @Ufile:Vw,Uo
3097  IF Ire=1 THEN OUTPUT @Refile;Fms,Rew
3100  IF (Im=1 OR Ok=1) AND Iplot=1 THEN OUTPUT @Plot:Qdp,Thetab
3103  IF Im=0 THEN
```

```
3106  BEEP
3109  INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
3112  Nrun=J
3115  IF Go_on=0 THEN 3130
3118  IF Go_on<>0 THEN Repeat
3121  ELSE
3124  IF J<Nrun+1 THEN Repeat
3127  END IF
3130  IF Im=0 THEN
3133  BEEP
3136  PRINT USING "10X,""NOTE: "",ZZ,"" data runs were stored in file "",10A";J-
1,D2_file$
3139  ASSIGN @File1 TO *
3142  OUTPUT @File2;Nrun-1
3145  ASSIGN @File1 TO D1_file$
3148  ENTER @File1;Date$,Ldtc1,Ldtc2,Itt
3151  OUTPUT @File2;Date$,Ldtc1,Ldtc2,Itt
3154  FOR I=1 TO Nrun-1
3157  IF Ihm=0 THEN
3160  ENTER @File1;Bop,Told$,Emf(*),Vr,Ir
3163  OUTPUT @File2;Bop,Told$,Emf(*),Vr,Ir
3166  ELSE
3169  ENTER @File1;Bop,Told$,Emf(*),Fms
3172  OUTPUT @File2;Bop,Told$,Emf(*),Fms
3175  END IF
3178  NEXT I
3181  ASSIGN @File1 TO *
3184  PURGE "DUMMY"
3187  END IF
3190  BEEP
3193  PRINT
3196* IF Iplot=1 THEN PRINT USING "10X,""NOTE: "",ZZ,"" X-Y pairs were stored in
 plot data file "",1
3199  ASSIGN @File2 TO *
3202  ASSIGN @Plot TO *
3205  IF Iuf=1 THEN ASSIGN @Ufile TO *
3208  IF Ire=1 THEN ASSIGN @Refile TO *
3211  CALL Stats
3214  BEEP
3217  INPUT "LIKE TO PLOT DATA (1=Y,0=N)?",Ok
3220  IF Ok=1 THEN CALL Plot
3223  SUBEND
3226!
3229! CURVE FITS OF PROPERTY FUNCTIONS
3232  DEF FNKcu(T)
3235! OFHC COPPER 250 TO 300 K
3238  Tk=T+273.15      !C TO K
3241  K=434-.112*Tk
3244  RETURN K
3247  FNEND
3250  DEF FNMu(T)
3253! 170 TO 360 K CURVE FIT OF VISCOUSITY
3256  Tk=T+273.15      !C TO K
3259  Mu=EXP(-4.4636+(1011.47/Tk))*1.0E-3
3262  RETURN Mu
3265  FNEND
3268  DEF FNCp(T)
3271! 180 TO 400 K CURVE FIT OF Cp
3274  Tk=T+273.15      !C TO K
3277  Cp=.40188+1.65007E-3*Tk+1.51494E-6*Tk^2-6.67853E-10*Tk^3
```

```
3280  Cp=Cp*1000
3283  RETURN Cp
3286  FNEND
3289  DEF FNRho(T)
3292  Tk=T+273.15      !C TO K
3295  X=1-(1.8*Tk/753.95)  !K TO R
3298  Ro=36.32+61.146414*X^(1/3)+16.418015*X+17.476838*X^.5+1.119828*X^2
3301  Ro=Ro/.062428
3304  RETURN Ro
3307  FNEND
3310  DEF FNPr(T)
3313  Pr=FNCp(T)*FNMu(T)/FNK(T)
3316  RETURN Pr
3319  FNEND
3322  DEF FNK(T)
3325! T<360 K WITH T IN C
3328  K=.071-.000261*T
3331  RETURN K
3334  FNEND
3337  DEF FNTanh(X)
3340  P=EXP(X)
3343  Q=1/P
3346  Tanh=(P-Q)/(P+Q)
3349  RETURN Tanh
3352  FNEND
3355  DEF FNTvsv(V)
3358  COM /Cc/ C(7),Ical
3361  T=C(0)
3364  FOR I=1 TO 7
3367  T=T+C(I)*V^I
3370  NEXT I
3373  IF Ical=1 THEN
3376  T=T-6.7422934E-2+T*(9.0277043E-3-T*(-9.3259917E-5))
3379  ELSE
3382  T=T+8.626897E-2+T*(3.76199E-3-T*5.0689259E-5)
3385  END IF
3388  RETURN T
3391  FNEND
3394  DEF FNBeta(T)
3397  Rop=FNRho(T+.1)
3400  Rom=FNRho(T-.1)
3403  Beta=-2/(Rop+Rom)*(Rop-Rom)/.2
3406  RETURN Beta
3409  FNEND
3412  DEF FNHfg(T)
3415  Hfg=1.3741344E+5-T*(3.3094361E+2+T*1.2165143)
3418  RETURN Hfg
3421  FNEND
3424  DEF FNPsat(Tc)
3427! 0 TO 80 deg F CURVE FIT OF Psat
3430  Tf=1.8*Tc+32
3433  Pa=5.945525+Tf*(.15352082+Tf*(1.4840963E-3+Tf*9.6150671E-6))
3436  Pg=Pa-14.7
3439  IF Pg>0 THEN       ! +=PSIG,-=in Hg
3442  Psat=Pg
3445  ELSE
3448  Psat=Pg*29.92/14.7
3451  END IF
3454  RETURN Psat
3457  FNEND
```

```
3460  DEF FNHsmooth(X,Bop,Isat)
3463  DIM A(5),B(5),C(5),D(5)
3466  DATA .20526,.25322,.319048,.55322,.79909,1.00258
3469  DATA .74515,.72992,.73189,.71225,.68472,.64197
3472  DATA .41092,.17726,.25142,.54806,.81916,1.0845
3475  DATA .71403,.72913,.72565,.696691,.665867,.61889
3478  READ A(*),B(*),C(*),D(*)
3481  IF Bop<6 THEN I=Bop
3484  IF Bop=6 THEN I=4
3487  IF Bop=10 THEN I=5
3490  IF Isat=1 THEN
3493  Hs=EXP(A(I)+B(I)*LOG(X))
3496  ELSE
3499  Hs=EXP(C(I)+D(I)*LOG(X))
3502  END IF
3505  RETURN Hs
3508  FNEND
3511  DEF FNPoly(X)
3514  COM /Cply/ A(10,10),C(10),B(4),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
3517  X1=X
3520  Poly=B(0)
3523  FOR I=1 TO Nop
3526  IF Ilog=1 THEN X1=LOG(X)
3529  Poly=Poly+B(I)*X1^I
3532  NEXT I
3535  IF Ilog=1 THEN Poly=EXP(Poly)
3538  RETURN Poly
3541  FNEND
3544  SUB Poly
3547  DIM R(10),S(10),Sy(12),Sx(12),Xx(100),Yy(100)
3550  COM /Cply/ A(10,10),C(10),B(4),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
3553  COM /Xxyy/ Xp(25),Yp(25)
3556  FOR I=0 TO 4
3559  B(I)=0
3562  NEXT I
3565  BEEP
3568  INPUT "SELECT (0=FILE,1=KEYBOARD,2=PROGRAM)",Im
3571  Im=Im+1
3574  BEEP
3577  INPUT "ENTER NUMBER OF X-Y PAIRS",Np
3580  IF Im=1 THEN
3583  BEEP
3586  INPUT "ENTER DATA FILE NAME",D_file$
3589  BEEP
3592  INPUT "LIKE TO EXCLUDE DATA PAIRS (1=Y,0=N)?",Ied
3595  IF Ied=1 THEN
3598  BEEP
3601  INPUT "ENTER NUMBER OF PAIRS TO BE EXCLUDED",Ipex
3604  END IF
3607  ASSIGN @File TO D_file$
3610  ELSE
3613  BEEP
3616  INPUT "WANT TO CREATE A DATA FILE (1=Y,0=N)?",Yes
3619  IF Yes=1 THEN
3622  BEEP
3625  INPUT "GIVE A NAME FOR DATA FILE",D_file$
3628  CREATE BDAT D_file$,5
3631  ASSIGN @File TO D_file$
3634  END IF
3637  END IF
```

```
3640  BEEP
3643  INPUT "ENTER THE ORDER OF POLYNOMIAL",N
3646  FOR I=0 TO N*2
3649  Sy(I)=0
3652  Sx(I)=0
3655  NEXT I
3658  IF Ied=1 AND Im=1 THEN
3661  FOR I=1 TO Ipex
3664  ENTER @File;X,Y
3667  NEXT I
3670  END IF
3673  FOR I=1 TO Np
3676  IF Im=1 THEN
3679  IF Opo=2 THEN ENTER @File;X,Y
3682  IF Opo<2 THEN ENTER @File;Y,X
3685  IF Opo=1 THEN Y=Y/X
3688  IF Ilog=1 THEN
3691  IF Opo=2 THEN Xt=X/Y
3694  X=LOG(X)
3697  IF Opo=2 THEN Y=LOG(Xt)
3700  IF Opo<2 THEN Y=LOG(Y)
3703  END IF
3706  END IF
3709  IF Im=2 THEN
3712  BEEP
3715  INPUT "ENTER NEXT X-Y PAIR",X,Y
3718  IF Yes=1 THEN OUTPUT @File;X,Y
3721  END IF
3724  IF Im<3 THEN
3727  Xx(I)=X
3730  Yy(I)=Y
3733  ELSE
3736  X=Xp(I-1)
3739  Y=Yp(I-1)
3742  END IF
3745  R(0)=Y
3748  Sy(0)=Sy(0)+Y
3751  S(1)=X
3754  Sx(1)=Sx(1)+X
3757  FOR J=1 TO N
3760  R(J)=R(J-1)*X
3763  Sy(J)=Sy(J)+R(J)
3766  NEXT J
3769  FOR J=2 TO N*2
3772  S(J)=S(J-1)*X
3775  Sx(J)=Sx(J)+S(J)
3778  NEXT J
3781  NEXT I
3784  IF Yes=1 AND Im=2 THEN
3787  BEEP
3790  PRINT USING "12X,DD,"" X-Y pairs were stored in file "",10A";Np,D_file$
3793  END IF
3796  Sx(0)=Np
3799  FOR I=0 TO N
3802  C(I)=Sy(I)
3805  FOR J=0 TO N
3808  A(I,J)=Sx(I+J)
3811  NEXT J
3814  NEXT I
3817  FOR I=0 TO N-1
3820  CALL Divide(I)
```

```
3823  CALL Subtract(I+1)
3826  NEXT I
3829  B(N)=C(N)/A(N,N)
3832  FOR I=0 TO N-1
3835  B(N-1-I)=C(N-1-I)
3838  FOR J=0 TO I
3841  B(N-1-I)=B(N-1-I)-A(N-1-I,N-J)*B(N-J)
3844  NEXT J
3847  B(N-1-I)=B(N-1-I)/A(N-1-I,N-1-I)
3850  NEXT I
3853 !PRINTER IS 701
3856 !PRINT B(*)
3859 !PRINTER IS 705
3862  IF Iprnt=0 THEN
3865  PRINT USING "12X,""EXPONENT    COEFFICIENT"""
3868  FOR I=0 TO N
3871  PRINT USING "15X,DD.5X,MD.7DE";I,B(I)
3874  NEXT I
3877  PRINT " "
3880  PRINT USING "12X,""DATA POINT       X               Y       Y(CALCULATED) DISCR
EPANCY"""
3883  FOR I=1 TO Np
3886  Yc=B(0)
3889  FOR J=1 TO N
3892  Yc=Yc+B(J)*Xx(I)^J
3895  NEXT J
3898  D=Yy(I)-Yc
3901  PRINT USING "15X,3D.4X,4(MD.5DE,1X)";I,Xx(I),Yy(I),Yc,D
3904  NEXT I
3907  END IF
3910  ASSIGN @File TO *
3913  SUBEND
3916  SUB Divide(M)
3919  COM /Cply/ A(10,10),C(10),B(4),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
3922  FOR I=M TO N
3925  Ao=A(I,M)
3928  FOR J=M TO N
3931  A(I,J)=A(I,J)/Ao
3934  NEXT J
3937  C(I)=C(I)/Ao
3940  NEXT I
3943  SUBEND
3946  SUB Subtract(K)
3949  COM /Cply/ A(10,10),C(10),B(4),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
3952  FOR I=K TO N
3955  FOR J=K-1 TO N
3958  A(I,J)=A(K-1,J)-A(I,J)
3961  NEXT J
3964  C(I)=C(K-1)-C(I)
3967  NEXT I
3970  SUBEND
3973  SUB Plin
3976  COM /Cply/ A(10,10),C(10),B(4),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
3979  COM /Xxyy/ Xx(25),Yy(25)
3982  PRINTER IS 705
3985  BEEP
3988  INPUT "WANT TO PLOT Uo vs Vw? (1=Y,0=N)",Iuo
3991  IF Iuo=0 THEN
3994  BEEP
3997  INPUT "SELECT (0=h/h0% same tube,1=h(HF)/h(sm)",Irt
```

```
4000  BEEP
4003  INPUT "SELECT h/h RATIO (1=FILE,0=COMPUTED)",Ihrat
4006  IF Ihrat=0 THEN
4009  BEEP
4012  INPUT "WHICH Tsat (1=6.7,0=-2.2)",Isat
4015  END IF
4018  Xmin=0
4021  Xmax=10
4024  Xstep=2
4027  IF Irt=0 THEN
4030  Ymin=0
4033  Ymax=1.4
4036  Ystep=.2
4039  ELSE
4042  Ymin=0
4045  Ymax=15
4048  Ystep=5
4051  END IF
4054  ELSE
4057  Opo=2
4060  Ymin=0
4063  Ymax=12
4066  Ystep=3
4069  Xmin=0
4072  Xmax=4
4075  Xstep=1
4078  END IF
4081  IF Ihrat=1 THEN
4084  Ymin=0
4087  Ymax=18
4090  Ystep=3
4093  Xmin=0
4096  Xmax=9
4099  Xstep=2
4102  END IF
4105  BEEP
4108  PRINT "IN:SP1:IP 2300,2200,8300,6800;"
4111  PRINT "SC 0,100,0,100;TL 2,0;"
4114  Sfx=100/(Xmax-Xmin)
4117  Sfy=100/(Ymax-Ymin)
4120  PRINT "PU 0,0 PD"
4123  FOR Xa=Xmin TO Xmax STEP Xstep
4126  X=(Xa-Xmin)*Sfx
4129  PRINT "PA";X,",0; XT;"
4132  NEXT Xa
4135  PRINT "PA 100,0;PU;"
4138  PRINT "PU PA 0,0 PD"
4141  FOR Ya=Ymin TO Ymax STEP Ystep
4144  Y=(Ya-Ymin)*Sfy
4147  PRINT "PA 0,";Y,"YT"
4150  NEXT Ya
4153  PRINT "PA 0,100 TL 0 2"
4156  FOR Xa=Xmin TO Xmax STEP Xstep
4159  X=(Xa-Xmin)*Sfx
4162  PRINT "PA";X,",100; XT"
4165  NEXT Xa
4168  PRINT "PA 100,100 PU PA 100,0 PD"
4171  FOR Ya=Ymin TO Ymax STEP Ystep
4174  Y=(Ya-Ymin)*Sfy
4177  PRINT "PD PA 100,",Y,"YT"
4180  NEXT Ya
```

```
4183  PRINT "PA 100,100 PU"
4186  PRINT "PA 0,-2 SR 1.5,2"
4189  FOR Xa=Xmin TO Xmax STEP Xstep
4192  X=(Xa-Xmin)*Sfx
4195  PRINT "PA";X,",0;"
4198  IF Iuo=0 THEN PRINT "CP -2,-1;LB";Xa;""
4201  IF Iuo=1 THEN PRINT "CP -1.5,-1;LB";Xa;""
4204  NEXT Xa
4207  PRINT "PU PA 0,0"
4210  FOR Ya=Ymin TO Ymax STEP Ystep
4213  IF ABS(Ya)<1.E-5 THEN Ya=0
4216  Y=(Ya-Ymin)*Sfy
4219  PRINT "PA 0,";Y,""
4222  IF Iuo=0 THEN PRINT "CP -4,-.25;LB";Ya;""
4225  IF Iuo=1 THEN PRINT "CP -3,-.25;LB";Ya;""
4228  NEXT Ya
4231  Xlabel$="Oil Percent"
4234  IF Iuo=0 THEN
4237  IF Irt=0 THEN
4240  Ylabel$="h/h0%"
4243  ELSE
4246  Ylabel$="h/hsmooth"
4249  END IF
4252  PRINT "SR 1.5,2;PU PA 50,-10 CP";-LEN(Xlabel$)/2;"0;LB";Xlabel$;""
4255  PRINT "PA -11,50 CP 0,";-LEN(Ylabel$)/2*5/6;"DI 0,1;LB";Ylabel$;""
4258  PRINT "CP 0,0"
4261  ELSE
4264  PRINT "SP0;SP2"
4267  PRINT "SR 1.2,2.4;PU PA -8,35;DI 0,1;LBU;PR 1,0.5;LBo;PR -1,0.5;LB (kW/m
"
4270  PRINT "PR -1,0.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,0;LBK)"
4273  PRINT "PA 42,-10;DI 1,0;LBV;PR .4,-1;LBw;PR 1,.5;LB(m/s)"
4276  PRINT "SP0;SP1"
4279  END IF
4282  Ipn=0
4285  BEEP
4288  INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Okp
4291  Icn=0
4294  IF Okp=1 THEN
4297  BEEP
4300  INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
4303! IF Iuo=0 THEN
4306  BEEP
4309  INPUT "SELECT (0=LINEAR, 1=LOG(X,Y)",Ilog
4312! END IF
4315  ASSIGN @File TO D_file$
4318  BEEP
4321  INPUT "ENTER THE BEGINNING RUN NUMBER",Md
4324  BEEP
4327  INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
4330  IF Iuo=0 AND Ihrat=0 THEN
4333  BEEP
4336  INPUT "ENTER DESIRED HEAT FLUX",Q
4339  END IF
4342  BEEP
4345  PRINTER IS 1
4348  PRINT USING "4X,""Select a symbol:"""
4351  PRINT USING "4X,""1  Star    2  Plus sign"""
4354  PRINT USING "4X,""3  Circle 4  Square"""
4357  PRINT USING "4X,""5  Rombus"""
```

```
4360  PRINT USING "4X,""6  Right-side-up triangle"""
4363  PRINT USING "4X,""7  Up-side-down triangle"""
4366  INPUT Sym
4369  PRINTER IS 705
4372  PRINT "PU DI"
4375  IF Sym=1 THEN PRINT "SM*"
4378  IF Sym=2 THEN PRINT "SM+"
4381  IF Sym=3 THEN PRINT "SMo"
4384  Nn=4
4387  IF Ilog=1 THEN Nn=1
4390  IF Md>1 THEN
4393  FOR I=1 TO (Md-1)
4396  ENTER @File;Xa,Ya
4399  NEXT I
4402  END IF
4405  IF Ihrat=0 THEN
4408  Q1=Q
4411  IF Ilog=1 THEN Q=LOG(Q)
4414  END IF
4417  FOR I=1 TO Npairs
4420  IF Iuo=0 AND Ihrat=0 THEN
4423  ENTER @File;Xa,B(*)
4426  Ya=B(0)
4429  FOR K=1 TO Nn
4432  Ya=Ya+B(K)*Q^K
4435  NEXT K
4438  END IF
4441  IF Iuo=1 OR Ihrat=1 THEN
4444  ENTER @File;Xa,Ya
4447  IF Iuo=1 THEN Ya=Ya/1000
4450  END IF
4453  IF Iuo=0 AND Ihrat=0 THEN
4456  IF Ilog=1 THEN Ya=EXP(Ya)
4459  IF Ilog=0 THEN Ya=Q1/Ya
4462  IF Irt=0 THEN
4465  IF Xa=0 THEN
4468  Yo=Ya
4471  Ya=1
4474  ELSE
4477  Ya=Ya/Yo
4480  END IF
4483  ELSE
4486  Hsm=FNHsmooth(Q,Xa,Isat)
4489  Ya=Ya/Hsm
4492  END IF
4495  END IF
4498  Xx(I-1)=Xa
4501  Yy(I-1)=Ya
4504  X=(Xa-Xmin)*Sfx
4507  Y=(Ya-Ymin)*Sfy
4510  IF Sym>3 THEN PRINT "SM"
4513  IF Sym<4 THEN PRINT "SR 1.4,2.4"
4516  PRINT "PA",X,Y,""
4519  IF Sym>3 THEN PRINT "SR 1.2,1.6"
4522  IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0,;"
4525  IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
4528  IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
4531  IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
4534  NEXT I
4537  BEEP
4540  ASSIGN @File TO *
```

```
4543  END IF
4546  PRINT "PU SM"
4549  BEEP
4552  INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Okp
4555  IF Okp=1 THEN
4558  BEEP
4561  PRINTER IS 1
4564  PRINT USING "4X,""Select line type:"""
4567  PRINT USING "6X,""0      Solid line"""
4570  PRINT USING "6X,""1      Dashed"""
4573  PRINT USING "6X,""2...5 Longer line - dash"""
4576  INPUT Ipn
4579  PRINTER IS 705
4582  BEEP
4585  INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
4588  Iprnt=1
4591  CALL Poly
4594  IF Iuo=1 THEN
4597  BEEP
4600  INPUT "DESIRE TO SET X Lower and Upper Limit (1=Y,0=N)?",Ixlim
4603  IF Ixlim=0 THEN
4606  Xll=0
4609  Xul=7
4612  END IF
4615  IF Ixlim=1 THEN
4618  BEEP
4621  INPUT "ENTER X Lower Limit",Xll
4624  BEEP
4627  INPUT "ENTER X Upper Limit",Xul
4630  END IF
4633  END IF
4636  FOR Xa=Xll TO Xul STEP Xstep/25
4639  Icn=Icn+1
4642  Ya=FNPoly(Xa)
4645  IF Iuo=1 THEN Ya=Ya/1000
4648  Y=(Ya-Ymin)*Sfy
4651  X=(Xa-Xmin)*Sfx
4654  IF Y<0 THEN Y=0
4657  IF Y>100 THEN GOTO 4687
4660  Pu=0
4663  IF Ipn=1 THEN Idf=Icn MOD 2
4666  IF Ipn=2 THEN Idf=Icn MOD 4
4669  IF Ipn=3 THEN Idf=Icn MOD 8
4672  IF Ipn=4 THEN Idf=Icn MOD 16
4675  IF Ipn=5 THEN Idf=Icn MOD 32
4678  IF Idf=1 THEN Pu=1
4681  IF Pu=0 THEN PRINT "PA",X,Y,"PD"
4684  IF Pu=1 THEN PRINT "PA",X,Y,"PU"
4687  NEXT Xa
4690  PRINT "PU"
4693  GOTO 4285
4696  END IF
4699  BEEP
4702  INPUT "WANT TO QUIT (1=Y,0=N)?",Iquit
4705  IF Iquit=1 THEN 4711
4708  GOTO 4285
4711  PRINT "PU SP0"
4714  SUBEND
4717  SUB Stats
4720  PRINTER IS 701
```

```
4723  J=0
4726  K=0
4729  BEEP
4732  IF Iplot=1 THEN ASSIGN @File TO P_file$
4735  BEEP
4738  INPUT "LAST RUN No?(0=QUIT)",Nn
4741  IF Nn=0 THEN 4849
4744  Nn=Nn-J
4747  Sx=0
4750  Sy=0
4753  Sz=0
4756  Sxs=0
4759  Sys=0
4762  Szs=0
4765  FOR I=1 TO Nn
4768  J=J+1
4771  ENTER @File;Q,T
4774  H=Q/T
4777  Sx=Sx+Q
4780  Sxs=Sxs+Q^2
4783  Sy=Sy+T
4786  Sys=Sys+T^2
4789  Sz=Sz+H
4792  Szs=Szs+H^2
4795  NEXT I
4798  Qave=Sx/Nn
4801  Tave=Sy/Nn
4804  Have=Sz/Nn
4807  Sdevq=SQR(ABS((Nn*Sxs-Sx^2)/(Nn*(Nn-1))))
4810  Sdevt=SQR(ABS((Nn*Sys-Sy^2)/(Nn*(Nn-1))))
4813  Sdevh=SQR(ABS((Nn*Szs-Sz^2)/(Nn*(Nn-1))))
4816  Sh=100*Sdevh/Have
4819  Sq=100*Sdevq/Qave
4822  St=100*Sdevt/Tave
4825  IF K=1 THEN 4843
4828  PRINT
4831  PRINT USING "11X,""DATA FILE:"",14A";File$
4834  PRINT
4837  PRINT USING "11X,""RUN Htube      SdevH   Qdp          SdevQ   Thetab SdevT""
"
4840  K=1
4843  PRINT USING "11X,DD,2(2X,D.3DE,1X,3D.2D),2X,DD.3D,1X,3D.2D";J,Have,Sh,Qave
,Sq,Tave,St
4846  GOTO 4735
4849  ASSIGN @File1 TO *
4852  PRINTER IS 1
4855  SUBEND
4858  SUB Coef
4861  COM /Cply/ A(10,10),C(10),B(4),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4864  BEEP
4867  INPUT "GIVE A NAME FOR CROSS-PLOT FILE",Cpf$
4870  CREATE BDAT Cpf$,2
4873  ASSIGN @File TO Cpf$
4876  BEEP
4879  INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
4882  BEEP
4885  INPUT "ENTER OIL PERCENT (-1=STOP)",Bop
4888  IF Bop<0 THEN 4900
4891  CALL Poly
4894  OUTPUT @File;Bop,B(*)
4897  GOTO 4882
```

```
4900  ASSIGN @File TO *
4903  SUBEND
4906  SUB Wilson(Cf,Ci)
4909  COM /Wil/ D2,Di,Do,L,Lu,Kcu
4912  DIM Emf(12)
4915! WLISON PLOT SUBROUTINE DETERMINE CF AND CI
4918  BEEP
4921  INPUT "ENTER DATA FILE NAME",File$
4924  BEEP
4927  PRINTER IS 1
4930  PRINT USING "4X,""Select option:"""
4933  PRINT USING "4X,""  0 Vary Cf and  Ci"""
4936  PRINT USING "4X,""  1 Fix  Cf Vary Ci"""
4939  PRINT USING "4X,""  2 Vary Cf Fix  Ci"""
4942  INPUT "ENTER OPTION",Icfix
4945  PRINTER IS 701
4948  IF Icfix=0 THEN 4960
4951  IF Icfix>0 THEN BEEP
4954  IF Icfix=1 THEN INPUT "ENTER Cf",Csf
4957  IF Icfix=2 THEN INPUT "ENTER CI",Ci
4960  PRINTER IS 1
4963  INPUT "Want To Vary Coeff?(1=Y,0=N)",Iccoef
4966  IF Iccoef=1 THEN INPUT "ENTER COEFF",R
4969  PRINTER IS 701
4972  IF Icfix=0 OR Icfix=2 THEN Cfa=.004
4975  IF Icfix=1 THEN Cfa=Csf
4978  Cia=Ci
4981  Xn=.3
4984  Fr=.3
4987  Jj=0
4990  Rr=3.
4993  IF Iccoef=1 THEN Rr=R
4996  PRINTER IS 1
4999  PRINT Do,Di,Kcu
5002  ASSIGN @File TO File$
5005  ENTER @File:Nrun,Date$,Ldtc1,Ldtc2,Itt
5008  Rw=Do*LOG(Do/Di)/(2*Kcu)
5011  Sx=0
5014  Sy=0
5017  Sxy=0
5020  Sx2=0
5023  Sy2=0
5026  FOR I=1 TO Nrun
5029  ENTER @File:Bop,Told$,Emf(*),Fms
5032! CONVERT EMF'S TO TEMPERATURE
5035  FOR J=1 TO 5
5038  T(J)=FNTvsv(Emf(J))
5041  NEXT J
5044  Tsat=(T(1)+T(2))*.5
5047  Tavg=T(5)
5050  Grad=37.3853+.104388*Tavg
5053  Tdrop=Emf(7)*1.E+6/(10.*Grad)
5056  Tavgc=T(5)-Tdrop*.5
5059  IF ABS(Tavg-Tavgc)>.01 THEN
5062  Tavg=(Tavg+Tavgc)*.5
5065  GOTO 5050
5068  END IF
5071!
5074! Compute properties of water
5077  Kw=FNKw(Tavg)
```

```
5080  Muwa=FNMuw(Tavg)
5083  Cpw=FNCpw(Tavg)
5086  Prw=FNPrw(Tavg)
5089  Rhow=FNRhow(Tavg)
5092!
5095! Compute properties of Freon-114
5098  Lmtd=Tdrop/LOG((T(5)-Tsat)/(T(5)-Tdrop-Tsat))
5101  IF Jj=0 THEN
5104  Tw=Tsat+Fr*Lmtd
5107  Thetab=Tw-Tsat
5110  Jj=1
5113  END IF
5116  Tf=(Tw+Tsat)*.5
5119  Rho=FNRho(Tf)
5122  Mu=FNMu(Tf)
5125  K=FNK(Tf)
5128  Cp=FNCp(Tf)
5131  Beta=FNBeta(Tf)
5134  Hfg=FNHfg(Tsat)
5137  Ni=Mu/Rho
5140  Alpha=K/(Rho*Cp)
5143  Pr=Ni/Alpha
5146!
5149! Analysis
5152! COMPUTE MDOT
5155  A=PI*(Do^2-Di^2)/4
5158  P=PI*Do
5161  Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
5164  Q=Mdot*Cpw*Tdrop
5167! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
5170! FOR UNENHANCED END(S)
5173  Hbar=190
5176  Fe=(Hbar*P/(Kcu*A))^.5*Lu
5179  Tanh=FNTanh(Fe)
5182  Theta=Thetab*Tanh/Fe
5185  Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni*Alpha))^.166667
5188  Yy=(1+(.559/Pr)^(9/16))^(8/27)
5191  Hbarc=K/Do*(.6+.387*Xx/Yy)^2
5194  IF ABS((Hbar-Hbarc)/Hbar)>.001 THEN
5197  Hbar=(Hbar+Hbarc)*.5
5200  GOTO 5176
5203  END IF
5206!
5209! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED ENDS
5212  Q1=(Hbar*P*Kcu*A)^.5*Thetab*Tanh
5215  Qc=Q-2*Q1
5218  As=PI*D2*L
5221! COMPUTE ACTUAL HEAT FLUX
5224  Qdp=Qc/As
5227  IF Icfix=0 OR Icfix>1 THEN Csf=1/Cf^(1./Rr)
5230  Thetab=Csf/Cp*Hfg*(Qdp/(Mu*Hfg)*(.014/(9.81*Rho))^.5)^(1/Rr)*Pr^1.7
5233  Ho=Qdp/Thetab
5236  Omega=Ho/Cf
5239  Uo=Q/(PI*Do*L*Lmtd)
5242  Vw=Mdot/(Rhow*PI*Di^2/4)
5245  Rew=Rhow*Vw*Di/Muwa
5248  Twi=Tw+Q*Rw/(PI*Do*L)
5251  Gama=Kw/Di*Rew^.8*Prw^(1/3.)*(Muwa/FNMuw(Twi))^.14
5254! PRINTER IS 1
5257  Yw=(1./Uo-Rw)*Omega
```

```
5260 Xw=Omega*Do/(Gama*Di)
5263 Sx=Sx+Xw
5266 Sy=Sy+Yw
5269 Sxy=Sxy+Yw*Xw
5272 Sx2=Sx2+Xw*Xw
5275 Sy2=Sy2+Yw*Yw
5278 NEXT I
5281 ASSIGN @File TO *
5284 M=(Sx*Sy-Nrun*Sxy)/(Sx*Sx-Nrun*Sx2)
5287 C=(Sy-Sx*M)/Nrun
5290 IF Icfix=0 OR Icfix=3 OR Icfix=4 THEN
5293 Cic=1/M
5296 Cfc=1/C
5299 END IF
5302 IF Icfix=1 THEN
5305 Cic=1/M
5308 Cfc=Cf
5311 END IF
5314 IF Icfix=2 THEN
5317 Cic=Ci
5320 Cfc=1/C
5323 END IF
5326 IF ABS((Ci-Cic)/Cic)>.001 OR ABS((Cf-Cfc)/Cfc)>.001 THEN
5329 Ci=(Ci+Cic)*.5
5332 Cf=(Cf+Cfc)*.5
5335 PRINTER IS 1
5338 PRINT USING "2X,"" Csf = "",MZ.3DE,2X,"" Ci = "",MZ.3DE":Csf,Ci
5341 PRINTER IS 701
5344 GOTO 5002
5347 END IF
5350 PRINT
5353 PRINTER IS 701
5356 PRINT USING "23X,""  Cf           Ci"""
5359 PRINT USING "8X,""ASSUMED       "",MZ.3DE,3X,MZ.3DE":Cfa,Cia
5362 PRINT USING "8X,""CALCULATED    "",MZ.3DE,3X,MZ.3DE":Csf,Ci
5365 PRINT
5368 Sum2=Sy2-2*M*Sxy-2*C*Sy+M^2*Sx2+2*M*C*Sx+Nrun*C^2
5371 PRINT USING "10X,""Sum of Squares = "",Z.3DE":Sum2
5374 PRINT USING "10X,""Coefficient = "",D.DDD":Rr
5377 SUBEND
5380 DEF FNMuw(T)
5383 A=247.8/(T+133.15)
5386 Mu=2.4E-5*10^A
5389 RETURN Mu
5392 FNEND
5395 DEF FNCpw(T)
5398 Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
5401 RETURN Cpw*1000
5404 FNEND
5407 DEF FNRhow(T)
5410 Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
5413 RETURN Ro
5416 FNEND
5419 DEF FNPrw(T)
5422 Prw=FNCpw(T)*FNMuw(T)/FNKw(T)
5425 RETURN Prw
5428 FNEND
5431 DEF FNKw(T)
5434 X=(T+273.15)/273.15
5437 Kw=-.92247+X*(2.8395-X*(1.8007-X*(.52577-.07344*X)))
```

```
5440  RETURN Kw
5443  FNEND
5446  SUB Plot
5449  COM /Cply/ A(10,10),C(10),B(4),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
5452  DIM Bs(3)
5455  INTEGER Ii
5458  PRINTER IS 1
5461  BEEP
5464  INPUT "SELECT HEATING MODE (0=ELECTRIC, 1=WATER)",Ihm
5467  Idv=0
5470  BEEP
5473  INPUT "LIKE DEFAULT VALUES FOR PLOT (1=Y,0=N)?",Idv
5476  Opo=0
5479  BEEP
5482  PRINT USING "4X,""Select Option:"""
5485  PRINT USING "6X,""0  q versus delta-T"""
5488  PRINT USING "6X,""1  h versus delta-T"""
5491  PRINT USING "6X,""2  h versus q"""
5494  INPUT Opo
5497  BEEP
5500  INPUT "SELECT UNITS (0=SI,1=ENGLISH)",Iun
5503  PRINTER IS 705
5506  IF Idv<>1 THEN
5509  BEEP
5512  INPUT "ENTER NUMBER OF CYCLES FOR X-AXIS",Cx
5515  BEEP
5518  INPUT "ENTER NUMBER OF CYCLES FOR Y-AXIS",Cy
5521  BEEP
5524  INPUT "ENTER MIN X-VALUE (MULTIPLE OF 10)",Xmin
5527  BEEP
5530  INPUT "ENTER MIN Y-VALUE (MULTIPLE OF 10)",Ymin
5533  ELSE
5536  IF Opo=0 THEN
5539  IF Ihm=1 THEN
5542  Cy=1
5545  Cx=2
5548  Xmin=1
5551  Ymin=10000
5554  ELSE
5557  Cy=3
5560  Cx=3
5563  Xmin=.1
5566  Ymin=100
5569  END IF
5572  END IF
5575  IF Opo=1 THEN
5578  IF Ihm=1 THEN
5581  Cy=2
5584  Cx=2
5587  Xmin=.1
5590  Ymin=100
5593  ELSE
5596  Cy=3
5599  Cx=2
5602  Xmin=1000
5605  Ymin=100
5608  END IF
5611  END IF
5614  IF Opo=2 THEN
5617  IF Ihm=1 THEN
5620  Cy=2
```

```
5623  Cx=1
5626  Xmin=10000
5629  Ymin=100
5632  ELSE
5635  Cy=3
5638  Cx=3
5641  Xmin=.1
5644  Ymin=100
5647  END IF
5650  END IF
5653  END IF
5656  BEEP
5659  PRINT "IN;SP1;IP 2300,2200,8300,6800;"
5662  PRINT "SC 0,100,0,100;TL 2,0;"
5665  Sfx=100/Cx
5668  Sfy=100/Cy
5671  BEEP
5674  INPUT "WANT TO BY-PASS CAGE? (1=Y,0=N)",Ibyp
5677  IF Ibyp=1 THEN 6049
5680  PRINT "PU 0,0 PD"
5683  Nn=9
5686  FOR I=1 TO Cx+1
5689  Xat=Xmin*10^(I-1)
5692  IF I=Cx+1 THEN Nn=1
5695  FOR J=1 TO Nn
5698  IF J=1 THEN PRINT "TL 2 0"
5701  IF J=2 THEN PRINT "TL 1 0"
5704  Xa=Xat*J
5707  X=LGT(Xa/Xmin)*Sfx
5710  PRINT "PA";X,",0; XT;"
5713  NEXT J
5716  NEXT I
5719  PRINT "PA 100,0;PU;"
5722  PRINT "PU PA 0,0 PD"
5725  Nn=9
5728  FOR I=1 TO Cy+1
5731  Yat=Ymin*10^(I-1)
5734  IF I=Cy+1 THEN Nn=1
5737  FOR J=1 TO Nn
5740  IF J=1 THEN PRINT "TL 2 0"
5743  IF J=2 THEN PRINT "TL 1 0"
5746  Ya=Yat*J
5749  Y=LGT(Ya/Ymin)*Sfy
5752  PRINT "PA 0,";Y,"YT"
5755  NEXT J
5758  NEXT I
5761  PRINT "PA 0,100 TL 0 2"
5764  Nn=9
5767  FOR I=1 TO Cx+1
5770  Xat=Xmin*10^(I-1)
5773  IF I=Cx+1 THEN Nn=1
5776  FOR J=1 TO Nn
5779  IF J=1 THEN PRINT "TL 0 2"
5782  IF J>1 THEN PRINT "TL 0 1"
5785  Xa=Xat*J
5788  X=LGT(Xa/Xmin)*Sfx
5791  PRINT "PA";X,",100; XT"
5794  NEXT J
5797  NEXT I
5800  PRINT "PA 100,100 PU PA 100,0 PD"
```

```
5803  Nn=9
5806  FOR I=1 TO Cy+1
5809  Yat=Ymin*10^(I-1)
5812  IF I=Cy+1 THEN Nn=1
5815  FOR J=1 TO Nn
5818  IF J=1 THEN PRINT "TL 0 2"
5821  IF J>1 THEN PRINT "TL 0 1"
5824  Ya=Yat*J
5827  Y=LGT(Ya/Ymin)*Sfy
5830  PRINT "PD PA 100,",Y,"YT"
5833  NEXT J
5836  NEXT I
5839  PRINT "PA 100,100 PU"
5842  PRINT "PA 0,-2 SR 1.5,2"
5845  Ii=LGT(Xmin)
5848  FOR I=1 TO Cx+1
5851  Xa=Xmin*10^(I-1)
5854  X=LGT(Xa/Xmin)*Sfx
5857  PRINT "PA";X,",0;"
5860  IF Ii>=0 THEN PRINT "CP -2,-2;LB10;PR -2,2;LB";Ii;""
5863  IF Ii<0 THEN PRINT "CP -2,-2;LB10;PR 0,2;LB";Ii;""
5866  Ii=Ii+1
5869  NEXT I
5872  PRINT "PU PA 0,0"
5875  Ii=LGT(Ymin)
5878  Y10=10
5881  FOR I=1 TO Cy+1
5884  Ya=Ymin*10^(I-1)
5887  Y=LGT(Ya/Ymin)*Sfy
5890  PRINT "PA 0,";Y,""
5893  PRINT "CP -4,-.25;LB10;PR -2,2;LB";Ii;""
5896  Ii=Ii+1
5899  NEXT I
5902  BEEP
5905  INPUT "WANT USE DEFAULT LABELS (1=Y,0=N)?",Idl
5908  IF Idl<>1 THEN
5911  BEEP
5914  INPUT "ENTER X-LABEL",Xlabel$
5917  BEEP
5920  INPUT "ENTER Y-LABEL",Ylabel$
5923  END IF
5926  IF Opo<2 THEN
5929  PRINT "SR 1,2:PU PA 40,-14:"
5932  PRINT "LB(T;PR -1.6,3 PD PR 1.2,0 PU;PR .5,-4;LBwo;PR .5,1;"
5935  PRINT "LB-T;PR .5,-1;LBsat;PR .5,1;"
5938  IF Iun=0 THEN
5941  PRINT "LB) (K)"
5944  ELSE
5947  PRINT "LB) (F)"
5950  END IF
5953  END IF
5956  IF Opo=2 THEN
5959  IF Iun=0 THEN
5962  PRINT "SR 1.5,2;PU PA 40,-14;LBq (W/m;SR 1,1.5;PR 0.5,1;LB2;SR 1.5,2;PR
0.5,-1;LB)"
5965  ELSE
5968  PRINT "SR 1.5,2;PU PA 34,-14;LBq (Btu/hr;PR .5,.5;LB.;PR .5,-.5;"
5971  PRINT "LBft;PR .5,1;SR 1,1.5;LB2;SR 1.5,2;PR .5,-1;LB);"
5974  END IF
5977  END IF
5980  IF Opo=0 THEN
```

```
5983  IF Iun=0 THEN
5986  PRINT "SR 1.5.2;PU PA -12.40:DI 0.1:LBq (W/m;PR -1,0.5:SR 1.1.5:LB2:SR 1
.5.2:PR 1,.5:LB)"
5989  ELSE
5992  PRINT "SR 1.5.2;PU PA -12.32:DI 0.1:LBq (Btu/hr:PR -.5,.5:LB.;PR .5,.5:"
5995  PRINT "LBft;SR 1.1.5;PR -1,.5:LB2;PR 1,.5;SR 1.5,2:LB)"
5998  END IF
6001  END IF
6004  IF Opo>0 THEN
6007  IF Iun=0 THEN
6010! PRINT "SR 1.5,2;PU PA -12,38:DI 0.1:LBh (W/m;PR -1,.5;SR 1,1.5;LB2;SR 1.
5.2:PR .5..5:"
6013  PRINT "SR 1.2,2.4;PU PA -12.37:DI 0,1:LBh;PR 1,0.5:LBo:PR -1,0.5:LB (W/m
"

6016  PRINT "PR -1,.5:SR 1,1.5:LB2:SR 1.5,2:PR .5..5:LB.;PR .5,0:LBK)"
6019  ELSE
6022  PRINT "SR 1.5.2:PU PA -12.28:DI 0.1:LBh (Btu/hr:PR -.5..5:LB.;PR .5,.5:"
6025  PRINT "LBft;PR -1,.5;SR 1,1.5:LB2:SR 1.5,2:PR .5,.5:LB.;PR .5,.5:LBF)"
6028  END IF
6031  END IF
6034  IF Idl=0 THEN
6037  PRINT "SR 1.5,2;PU PA 50.-16 CP";-LEN(Xlabel$)/2;"0:LB";Xlabel$;""
6040  PRINT "PA -14.50 CP 0,";-LEN(Ylabel$)/2+5/6;"DI 0,1:LB";Ylabel$;""
6043  PRINT "CP 0,0 DI"
6046  END IF
6049  Ipn=0
6052  Xll=1.E+6
6055  Xul=-1.E+6
6058  Icn=0
6061  Ifn=0
6064  Ijoin=1
6067  BEEP
6070  INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Ok
6073  IF Ok=1 THEN
6076  BEEP
6079  INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
6082  ASSIGN @File TO D_file$
6085  BEEP
6088  BEEP
6091  INPUT "ENTER THE BEGINNING RUN NUMBER",Md
6094  BEEP
6097  INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
6100! BEEP
6103! INPUT "CONNECT DATA WITH LINE (1=Y,0=N)?",Icl
6106  BEEP
6109  PRINTER IS 1
6112  PRINT USING "4X,""Select a symbol:"""
6115  PRINT USING "6X,""1  Star     2  Plus sign"""
6118  PRINT USING "6X,""3  Circle   4  Square"""
6121  PRINT USING "6X,""5  Rombus"""
6124  PRINT USING "6X,""6  Right-side-up triangle"""
6127  PRINT USING "6X,""7  Up-side-down triangle"""
6130  INPUT Sym
6133  PRINTER IS 705
6136  PRINT "PU DI"
6139  IF Sym=1 THEN PRINT "SM*"
6142  IF Sym=2 THEN PRINT "SM+"
6145  IF Sym=3 THEN PRINT "SMo"
6148  IF Md>1 THEN
6151  FOR I=1 TO (Md-1)
```

```
6154  ENTER @File:Ya,Xa
6157  NEXT I
6160  END IF
6163  FOR I=1 TO Npairs
6166  ENTER @File:Ya,Xa
6169  IF I=1 THEN Q1=Ya
6172  IF I=Npairs THEN Q2=Ya
6175  IF Opo=1 THEN Ya=Ya/Xa
6178  IF Opo=2 THEN
6181  Q=Ya
6184  Ya=Ya/Xa
6187  Xa=Q
6190  END IF
6193  IF Xa<Xll THEN Xll=Xa
6196  IF Xa>Xul THEN Xul=Xa
6199  IF Iun=1 THEN
6202  IF Opo<2 THEN Xa=Xa*1.8
6205  IF Opo>0 THEN Ya=Ya*.1761
6208  IF Opo=0 THEN Ya=Ya*.317
6211  IF Opo=2 THEN Xa=Xa*.317
6214  END IF
6217  X=LGT(Xa/Xmin)*Sfx
6220  Y=LGT(Ya/Ymin)*Sfy
6223  Kj=0
6226  CALL Symb(X,Y,Sym,Icl,Kj)
6229  GOTO 6268
6232  IF Sym>3 THEN PRINT "SM"
6235  IF Sym<4 THEN PRINT "SR 1.4,2.4"
6238  IF Icl=0 THEN
6241  PRINT "PA",X,Y,""
6244  ELSE
6247  PRINT "PA",X,Y,"PD"
6250  END IF
6253  IF Sym>3 THEN PRINT "SR 1.2,1.6"
6256  IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0;"
6259  IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
6262  IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
6265  IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
6268  NEXT I
6271  PRINT "PU"
6274  BEEP
6277  INPUT "WANT TO LABEL? (1=Y,0=N)",Ilab
6280  IF Ilab=1 THEN
6283  PRINT "SP0;SP2"
6286  BEEP
6289  IF Klab=0 THEN
6292  Xlab=5
6295  Ylab=85
6298  INPUT "ENTER INITIAL X,Y LOCATIONS",Xlab,Ylab
6301  Xtt=Xlab-5
6304  Ytt=Ylab+8
6307  PRINT "SR 1,1.5"
6310  BEEP
6313  INPUT "SELECT LABEL TYPE (0=FILE NAME, 1=TUBE TYPE)",Ifntt
6316  IF Ifntt=0 THEN
6319  PRINT "SM;PA",Xtt,Ytt,"LB       %   Heat  File"
6322  Ytt=Ytt-3
6325  PRINT "SM;PA",Xtt,Ytt,"LB       %   Heat  File"
6328  ELSE
6331  PRINT "SM;PA",Xtt,Ytt,"LB       %   Heat  Tube"
```

```
6334  Ytt=Ytt-3
6337  PRINT "PA",Xtt,Ytt,"LB      Oil  Flux  Type"
6340  END IF
6343  IF Sym=1 THEN PRINT "SM*"
6346  IF Sym=2 THEN PRINT "SM+"
6349  IF Sym=3 THEN PRINT "SMo"
6352  Klab=1
6355  END IF
6358  Kj=1
6361  CALL Symb(Xlab,Ylab,Sym,Icl,Kj)
6364  PRINT "SR 1,1.5:SM"
6367  IF Sym<4 THEN PRINT "PR 2,0"
6370  BEEP
6373  INPUT "ENTER BOP",Bop
6376  IF Ifntt=1 THEN
6379  BEEP
6382  INPUT "ENTER TUBE TYPE",Ttype$
6385  END IF
6388  IF Bop<10 THEN PRINT "PR 2,0;LB";Bop;""
6391  IF Bop>9 THEN PRINT "PR .5,0;LB";Bop;""
6394  Ihf=0
6397  IF Q1>Q2 THEN Ihf=1
6400  IF Ihf=0 THEN PRINT "PR 4,0;LBInc"
6403  IF Ihf=1 THEN PRINT "PR 4,0;LBDec"
6406  IF Ifntt=0 THEN
6409  PRINT "PR 2,0;LB";D_file$;""
6412  ELSE
6415  PRINT "PR 2,0;LB";Ttype$;""
6418  END IF
6421  PRINT "SP0;SP1;SR 1.5,2"
6424  Ylab=Ylab-5
6427  END IF
6430  BEEP
6433  ASSIGN @File TO *
6436  Xll=Xll/1.2
6439  Xul=Xul*1.2
6442! GOTO 8040
6445  END IF
6448  PRINT "PU SM"
6451  BEEP
6454  INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Go_on
6457  IF Go_on=1 THEN
6460  BEEP
6463  PRINTER IS 1
6466  PRINT USING "4X,""Select line type:"""
6469  PRINT USING "6X,""0      Solid line"""
6472  PRINT USING "6X,""1      Dashed"""
6475  PRINT USING "6X,""2,,,5 Longer line - dash"""
6478  INPUT Ipn
6481  PRINTER IS 705
6484  BEEP
6487  INPUT "SELECT (0=LIN,1=LOG(X,Y))",Ilog
6490  Iprnt=1
6493  CALL Poly
6496  IF Ifn=0 THEN
6499  Njoin=1
6502  BEEP
6505  INPUT "ENTER NUMBER OF FILES TO JOIN?",Njoin
6508  END IF
6511  Ijoin=0
6514  IF Ifn<Njoin THEN Ijoin=1
```

```
6517  IF Ifn=0 OR Ijoin=1 THEN
6520  FOR Ij=0 TO 3
6523  Bs(Ij)=Bs(Ij)+B(Ij)
6526  NEXT Ij
6529  Ifn=Ifn+1
6532  END IF
6535  IF Njoin=Ifn THEN
6538  FOR Ij=0 TO 3
6541  B(Ij)=Bs(Ij)/Njoin
6544  Bs(Ij)=0
6547  NEXT Ij
6550  Ifn=0
6553  ELSE
6556  GOTO 6067
6559  END IF
6562  BEEP
6565  INPUT "ENTER Y LOWER AND UPPER LIMITS",Yll,Yul
6568  FOR Xx=0 TO Cx STEP Cx/200
6571  Xa=Xmin*10^Xx
6574  IF Xa<Xll OR Xa>Xul THEN 6655
6577  Icn=Icn+1
6580  Pu=0
6583  IF Ipn=1 THEN Idf=Icn MOD 2
6586  IF Ipn=2 THEN Idf=Icn MOD 4
6589  IF Ipn=3 THEN Idf=Icn MOD 8
6592  IF Ipn=4 THEN Idf=Icn MOD 16
6595  IF Ipn=5 THEN Idf=Icn MOD 28
6598  IF Idf=1 THEN Pu=1
6601  IF Opo=0 THEN Ya=FNPoly(Xa)
6604  IF Opo=2 AND Ilog=0 THEN Ya=Xa/FNPoly(Xa)
6607  IF Opo=2 AND Ilog=1 THEN Ya=FNPoly(Xa)
6610  IF Opo=1 THEN Ya=FNPoly(Xa)
6613  IF Ya<Ymin THEN 6655
6616  IF Ya<Yll OR Ya>Yul THEN 6655
6619  IF Iun=1 THEN
6622  IF Opo<2 THEN Xa=Xa*1.8
6625  IF Opo>0 THEN Ya=Ya*.1761
6628  IF Opo=0 THEN Ya=Ya*.317
6631  IF Opo=2 THEN Xa=Xa*.317
6634  END IF
6637  Y=LGT(Ya/Ymin)*Sfy
6640  X=LGT(Xa/Xmin)*Sfx
6643  IF Y<0 THEN Y=0
6646  IF Y>100 THEN GOTO 6655
6649  IF Pu=0 THEN PRINT "PA",X,Y,"PD"
6652  IF Pu=1 THEN PRINT "PA",X,Y,"PU"
6655  NEXT Xx
6658  PRINT "PU"
6661  GOTO 6067
6664  END IF
6667  BEEP
6670  INPUT "WANT TO PLOT REILLY'S SMOOTH-TUBE DATA? (1=Y,0=N)",Irly
6673  IF Opo=0 OR Opo=1 THEN
6676  Xll=3
6679  Xul=20
6682  END IF
6685  IF Opo=2 THEN
6688  Xll=10000
6691  Xul=100000
6694  END IF
```

```
6697  IF Irly=1 THEN
6700  Yll=20
6703  Yul=70
6706  BEEP
6709  INPUT "ENTER LOWER AND UPPER Y-LIMITS FOR PLOTTING",Yll,Yul
6712  FOR Xx=0 TO Cx STEP Cx/200
6715  Xa=Xmin*10^Xx
6718  IF Xa<Xll OR Xa>Xul THEN 6757
6721  Xl=LOG(Xa)
6724  IF Opo=0 THEN Yl=-2.5402837E-1+Xl*(4.9720151-Xl*2.5134787E-1)
6727  IF Opo=1 THEN Yl=-2.5402837E-1+Xl*(3.9720151-Xl*2.5134787E-1)
6730  IF Opo=2 THEN Yl=-3.7073801E-1+Xl*(8.7259190E-1-Xl*6.8826842E-3)
6733  Ya=EXP(Yl)
6736  Y=LGT(Ya/Ymin)*Sfy
6739  X=LGT(Xa/Xmin)*Sfx
6742  Ipu=0
6745  IF Y<Yll THEN Ipu=1
6748  IF Y>Yul THEN GOTO 6757
6751  IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
6754  IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
6757  NEXT Xx
6760  PRINT "PU"
6763  END IF
6766  BEEP
6769  INPUT "WANT TO PLOT ROHSENOW CORRELATION? (1=Y,0=N)",Irohs
6772  IF Irohs=1 THEN
6775  Yll=15
6778  Yul=80
6781  BEEP
6784  INPUT "ENTER Tsat (Deg C)",Tsat
6787  Csf=.0040
6790  BEEP
6793  INPUT "ENTER Csf (DEF=0.004)",Csf
6796  Tf=Tsat+2
6799  FOR Xx=0 TO Cx STEP Cx/200
6802  Xa=Xmin*10^Xx
6805  IF Xa<Xll OR Xa>Xul THEN 6889
6808  Xl=LOG(Xa)
6811  IF Opo<2 THEN Tf=Tsat+Xa/2
6814  Rho=FNRho(Tf)
6817  K=FNK(Tf)
6820  Mu=FNMu(Tf)
6823  Cp=FNCp(Tf)
6826  Hfg=FNHfg(Tsat)
6829  Ni=Mu/Rho
6832  Pr=Cp*Mu/K
6835  Omega=Csf*Hfg/Cp*((.014/(9.81*Rho))^.5/(Mu*Hfg))^(1./3)*Pr^1.7
6838  IF Opo=0 THEN Ya=(Xa/Omega)^3
6841  IF Opo=1 THEN Ya=(Xa/Omega)^3/Xa
6844  IF Opo=2 THEN Ya=Xa^(2./3)/Omega
6847  IF Opo=2 THEN
6850  Tfc=Tsat+Xa/Ya*.5
6853  IF ABS(Tf-Tfc)>.01 THEN
6856  Tf=(Tf+Tfc)*.5
6859  GOTO 6814
6862  END IF
6865  END IF
6868  Y=LGT(Ya/Ymin)*Sfy
6871  X=LGT(Xa/Xmin)*Sfx
6874  Ipu=0
```

```
7060  PRINT
7063  PRINT USING "10X,"" Fms      Tin      Tev      Vw^2     Tdrop"""
7066  IF K=0 THEN
7069  PRINTER IS 701
7072  PRINT
7075  PRINT "           Month, date and time: ";Date$
7078  IF Itt=0 THEN PRINT USING "10X,""Tube Type:             Wieland Smooth"""
7081  IF Itt=1 THEN PRINT USING "10X,""Tube Type:             High Flux"""
7084  IF Itt=2 THEN PRINT USING "10X,""Tube Type:             Turbo-B"""
7087  PRINT
7090  PRINT USING "10X,"" Fms      Tin      Tev      Vw^2      Tdrop"""
7093  PRINTER IS 1
7096  K=1
7099  END IF
7102  BEEP
7105  INPUT "ENTER FLOWMETER READING",Fms
7108  OUTPUT 709;"AR AF0 AL4 VR1"
7111  FOR L=0 TO 4
7114  OUTPUT 709;"AS SA"
7117  IF L>0 AND L<4 THEN 7141
7120  S=0
7123  FOR I=0 TO 9
7126  ENTER 709:E
7129  S=S+E
7132  NEXT I
7135  IF L=0 THEN Emf(0)=ABS(S/10)
7138  IF L=4 THEN Emf(1)=ABS(S/10)
7141  NEXT L
7144  OUTPUT 709;"AR AF20 AL20 VR1"
7147  OUTPUT 709;"AS SA"
7150  Etp=0
7153  FOR I=0 TO 9
7156  ENTER 709:Et
7159  Etp=Etp+Et
7162  NEXT I
7165  Etp=Etp/10
7168  Tin=FNTvsv(Emf(1))
7171  Tev=FNTvsv(Emf(0))
7174  Grad=37.9853+.104388*Tin
7177  Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
7180  Vw=Mdot/(1000*PI*Di^2)*4
7183  Tdrop=Etp*1.E+6/(10*Grad)
7186  PRINT USING "10X,3(DD.DD,4X),1X,Z.DD,4X,MZ.4D";Fms,Tin,Tev,Vw^2,Tdrop
7189  BEEP
7192  INPUT "WANT TO ACCEPT THIS DATA SET? (1=Y,0=N)",Ok
7195  J=J+1
7198  IF Ok=0 THEN
7201  J=J-1
7204  GOTO 7102
7207  ELSE
7210  OUTPUT @File;Fms,Emf(*),Etp
7213  PRINTER IS 701
7216  PRINT USING "10X,3(DD.DD,4X),1X,Z.DD,4X,MZ.4D";Fms,Tin,Tev,Vw^2,Tdrop
7219  PRINTER IS 1
7222  BEEP
7225  INPUT "WILL THERE BE ANOTHER DATA SET? (1=Y,0=N)",Go_on
7228  IF Go_on=1 THEN 7102
7231  END IF
7234  ASSIGN @File TO *
```

```
7237  PRINTER IS 701
7240  PRINT
7243  PRINT USING "10X,""NOTE: "",ZZ,"" data sets are stored in file "",15A";J,F
ile$
7246  PRINTER IS 1
7249  SUBEND
7252  SUB Uoprt
7255  PRINTER IS 1
7258  BEEP
7261  INPUT "Enter Uo File Name",File$
7264  BEEP
7267  INPUT "Number of Data Runs",Nrun
7270  INPUT "Do You Want a Plot File?(1=Y,0=N)",Iplot
7273  BEEP
7276  IF Iplot=1 THEN
7279  INPUT "Give Plot File Name",P_file$
7282  CREATE BDAT P_file$,4
7285  ASSIGN @Plot TO P_file$
7288  END IF
7291  PRINTER IS 701
7294  PRINT
7297  PRINT
7300  PRINT USING "10X,""   Water Vel        Uo"""
7303  ASSIGN @File TO File$
7306  IF Iplot=1 THEN ASSIGN @File1 TO P_file$
7309  FOR I=1 TO Nrun
7312  ENTER @File;Vw,Uo
7315  IF Iplot=1 THEN OUTPUT @File1;Vw,Uo
7318  PRINT USING "15X,D.DD,6X,MZ.3DE";Vw,Uo
7321  NEXT I
7324  ASSIGN @File TO *
7327  ASSIGN @File1 TO *
7330  PRINT USING "10X,""NOTE: "",ZZ,"" data sets are stored in file "",15A";Nru
n,File$
7333  IF Iplot=1 THEN
7336  PRINT USING "10X,""NOTE: "",ZZ,"" X-Y Pairs are stored in file "",15A";Nru
n,P_file$
7339  END IF
7342  PRINTER IS 1
7345  SUBEND
7348  SUB Select
7351  COM /Idp/ Idp
7354  BEEP
7357  PRINTER IS 1
7360  PRINT USING "4X,""Select option:"""
7363  PRINT USING "6X,"" 0 Taking data or re-processing old data"""
7366  PRINT USING "6X,"" 1 Plotting data on Log-Log """
7369  PRINT USING "6X,"" 2 Plotting data on Linear"""
7372  PRINT USING "6X,"" 3 Make cross-plot coefft file"""
7375  PRINT USING "6X,"" 4 Re-circulate water"""
7378  PRINT USING "6X,"" 5 Purge"""
7381  PRINT USING "6X,"" 6 T-Drop correction"""
7384  PRINT USING "6X,"" 7 Print Uo File"""
7387  PRINT USING "6X,"" 8 Modify X-Y file"""
7390  PRINT USING "6X,"" 9 Move"""
7393  PRINT USING "6X,""10 Comb"""
7396  PRINT USING "6X,""11 Fixup"""
7399  INPUT Idp
7402  IF Idp=0 THEN CALL Main
7405  IF Idp=1 THEN CALL Plot
```

```
7408  IF Idp=2 THEN CALL Plin
7411  IF Idp=3 THEN CALL Coef
7414  IF Idp=4 THEN CALL Main
7417  IF Idp=5 THEN CALL Purg
7420  IF Idp=6 THEN CALL Tdcn
7423  IF Idp=7 THEN CALL Uoprt
7426  IF Idp=8 THEN CALL Xymod
7429  IF Idp=9 THEN CALL Move
7432  IF Idp=10 THEN CALL Comb
7435  IF Idp=11 THEN CALL Fixup
7438  SUBEND
7441  SUB Xymod
7444  PRINTER IS 1
7447  BEEP
7450  INPUT "ENTER FILE NAME",File$
7453  ASSIGN @File1 TO File$
7456  BEEP
7459  INPUT "ENTER NUMBER OF X-Y PAIRS",Np
7462  BEEP
7465  INPUT "ENTER NEW FILE NAME",File2$
7468  CREATE BDAT File2$,5
7471  ASSIGN @File2 TO File2$
7474  BEEP
7477  INPUT "ENTER NUMBER OF X-Y PAIRS TO BE DELETED",Ndel
7480  IF Ndel=0 THEN 7492
7483  FOR I=1 TO Ndel
7486  BEEP
7489  INPUT "ENTER DATA SET NUMBER TO BE DELETED",Nd(I)
7492  NEXT I
7495  FOR J=1 TO Np
7498  ENTER @File1;X,Y
7501  FOR I=1 TO Ndel
7504  IF Nd(I)=J THEN 7516
7507  NEXT I
7510  OUTPUT @File2;X,Y
7513  PRINT J,X,Y
7516  NEXT J
7519  PRINTER IS 701
7522  ASSIGN @File1 TO *
7525  ASSIGN @File2 TO *
7528  SUBEND
7531  SUB Move
7534! FILE NAME: MOVE
7537!
7540  DIM Bop(66),A(66),B(66),C(66),D(66),E(66),F(66),G(66),H(66),J(66),K(66),L(
66),M(66)
7543  DIM Told$(66)[14],N(66),Vr(66),Ir(66)
7546  BEEP
7549  INPUT "OLD FILE TO MOVE",D2_file$
7552  ASSIGN @File2 TO D2_file$
7555  ENTER @File2;Nrun,Date$,Ldtc1,Ldtc2,Itt
7558  FOR I=1 TO Nrun
7561  ENTER @File2;Bop(I),Told$(I)
7564  ENTER @File2;A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),N
(I)
7567  ENTER @File2:Vr(I),Ir(I)
7570  NEXT I
7573  ASSIGN @File2 TO *
7576  BEEP
7579  INPUT "SHIFT DISK AND HIT CONTINUE",Ok
```

```
7582  BEEP
7585  INPUT "INPUT BDAT SIZE",Size
7588  CREATE BDAT D2_file$,Size
7591  ASSIGN @File1 TO D2_file$
7594  OUTPUT @File1;Nrun,Date$,Ldtc1,Ldtc2,Itt
7597  FOR I=1 TO Nrun
7600  OUTPUT @File1;Bop(I),Told$(I)
7603  OUTPUT @File1:A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),
N(I)
7606  OUTPUT @File1;Vr(I),Ir(I)
7609  NEXT I
7612  ASSIGN @File1 TO *
7615! RENAME "TEST" TO D2_file$
7618  BEEP 2000,.2
7621  BEEP 4000,.2
7624  BEEP 4000,.2
7627  PRINT "DATA FILE MOVED"
7630  SUBEND
7633  SUB Comb
7636! FILE NAME: COMB
7639!
7642  DIM Emf(12)
7645  BEEP
7648  INPUT "OLD FILE TO FIXUP",D2_file$
7651  ASSIGN @File2 TO D2_file$
7654  D1_file$="TEST"
7657  CREATE BDAT D1_file$,30
7660  ASSIGN @File1 TO D1_file$
7663  ENTER @File2:Nrun,Date$,Ldtc1,Ldtc2,Itt
7666  IF K=0 THEN OUTPUT @File1;Nrun,Date$,Ldtc1,Ldtc2,Itt
7669  FOR I=1 TO Nrun
7672  ENTER @File2:Bop,Told$,Emf(*),Vr,Ir
7675  OUTPUT @File1:Bop,Told$,Emf(*),Vr,Ir
7678  NEXT I
7681  ASSIGN @File2 TO *
7684! RENAME "TEST" TO D2_file$
7687  BEEP 2000,.2
7690  BEEP 4000,.2
7693  BEEP 4000,.2
7696  BEEP
7699  INPUT "WANT TO ADD ANOTHER FILE (1=Y,0=N)?",Oka
7702  IF Oka=1 THEN
7705  K=1
7708  BEEP
7711  INPUT "GIVE NEW FILE NAME",Nfile$
7714  ASSIGN @File2 TO Nfile$
7717  GOTO 7663
7720  END IF
7723  ASSIGN @File2 TO *
7726  SUBEND
7729  SUB Fixup
7732! FILE: FIXUP
7735! DATE: February 18, 1986
7738!
7741  DIM Emf(12)
7744  BEEP
7747  INPUT "OLD FILE TO FIXUP",D2_file$
7750  ASSIGN @File2 TO D2_file$
7753  D1_file$="TEST"
7756  CREATE BDAT D1_file$,20
7759  ASSIGN @File1 TO D1_file$
```

```
7762  ENTER @File2:Nrun.Date$.Ldtc1.Ldtc2.Itt
7765  Nruno=27
7768  OUTPUT @File1:Nruno.Date$.Ldtc1.Ldtc2.Itt
7771  FOR I=1 TO Nrun
7774  ENTER @File2:Bop.Told$.Emf(*).Vr.Ir
7777  IF I=1 THEN 7783
7780  OUTPUT @File1;Bop.Told$,Emf(*),Vr.Ir
7783  NEXT I
7786  ASSIGN @File2 TO *
7789  ASSIGN @File1 TO *
7792! RENAME "TEST" TO D2_file$
7795  BEEP 2000..2
7798  BEEP 4000..2
7801  BEEP 4000,.2
7804  SUBEND
```

APPENDIX C

EXAMPLES OF REPRESENTATIVE DATA RUNS

The two following data runs (TXE222 and GTB185) are representative samples of the data taken over the course of the investigation. The first data run for the Thermoexcel-E surface was for a decreasing heat-flux condition and an oil concentration of three percent. The second data run was for the GEWA-T surface was also for a decreasing heat-flux condition but with an oil concentration of one percent.

```
Month, date and time :05:06:11:41:20

NOTE: Program name : DRP4
      Disk number  = 13
      Old file name: TXE222
      This data set taken on : 02:18:13:42:58
      Tube Number:    10

Data Set Number =   1  Bulk Oil % =  3.0      02:18:13:48:44
TC No:     1       2        3       4        5       6       7       8
Temp :    8.71    9.45    9.00    8.48    9.70    8.12   10.21    8.59
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
  8.74   2.23     2.17    2.06  -1.77   -18.9
 Thetab  Htube        Qdp
  6.541  1.455E+04  9.519E+04

Data Set Number =   2  Bulk Oil % =  3.0      02:18:13:49:57
TC No:     1       2        3       4        5       6       7       8
Temp :    8.51    9.01    8.42    8.00    9.68    8.29   10.33    8.51
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
  8.55   2.24     2.22    2.09  -1.73   -18.3
 Thetab  Htube        Qdp
  6.319  1.508E+04  9.531E+04

Data Set Number =   3  Bulk Oil % =  3.0      02:18:13:50:51
TC No:     1       2        3       4        5       6       7       8
Temp :    8.68    8.88    8.33    7.89    9.84    8.07   10.22    8.64
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
  8.53   2.26     2.19    2.07  -1.74   -18.8
 Thetab  Htube        Qdp
  6.305  1.511E+04  9.526E+04

Data Set Number =   4  Bulk Oil % =  3.0      02:18:14:02:37
TC No:     1       2        3       4        5       6       7       8
Temp :    6.93    7.05    6.71    6.48    7.23    6.24    7.63    6.56
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
  6.66   2.25     2.21    2.14  -1.73   -18.5
 Thetab  Htube        Qdp
  4.433  1.414E+04  6.269E+04

Data Set Number =   5  Bulk Oil % =  3.0      02:18:14:03:13
TC No:     1       2        3       4        5       6       7       8
Temp :    6.32    7.18    6.30    6.56    7.35    6.25    7.65    6.52
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
  6.71   2.28     2.25    2.18  -1.69   -18.4
 Thetab  Htube        Qdp
  4.444  1.408E+04  6.258E+04

Data Set Number =   6  Bulk Oil % =  3.0      02:18:14:13:56
TC No:     1       2        3       4        5       6       7       8
Temp :    5.50    5.65    5.41    5.26    5.58    4.90    5.84    5.06
 Twa     Tliqd   Tliqd2  Tvapr   Psat    Tsump
  5.28   2.32     2.28    2.35  -1.66   -16.3
 Thetab  Htube        Qdp
  2.981  1.304E+04  3.388E+04
```

```
Data Set Number =  7  Bulk Oil % =  3.0     02:18:14:14:29
TC No:     1      2      3      4      5      6      7      8
Temp :   5.45   5.60   5.37   5.31   5.61   4.88   5.82   5.02
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
 5.26    2.29     2.26    2.35   -1.68   -16.2
 Thetab  Htube        Qdp
 2.987   1.299E+04  3.381E+04

Data Set Number =  8  Bulk Oil % =  3.0     02:18:14:20:33
TC No:     1      2      3      4      5      6      7      8
Temp :   4.25   4.33   4.22   4.16   4.49   4.07   4.58   4.06
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
 4.20    2.24     2.16    2.64   -1.77   -15.8
 Thetab  Htube        Qdp
 1.998   1.176E+04  2.349E+04

Data Set Number =  9  Bulk Oil % =  3.0     02:18:14:21:05
TC No:     1      2      3      4      5      6      7      8
Temp :   4.33   4.41   4.26   4.23   4.52   4.10   4.65   4.11
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
 4.25    2.28     2.23    2.71   -1.71   -15.8
 Thetab  Htube        Qdp
 2.004   1.169E+04  2.344E+04

Data Set Number =  10  Bulk Oil % =  3.0     02:18:14:26:17
TC No:     1      2      3      4      5      6      7      8
Temp :   3.68   3.68   3.59   3.54   3.80   3.51   3.85   3.47
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
 3.59    2.33     2.27    2.95   -1.66   -16.4
 Thetab  Htube        Qdp
 1.293   1.137E+04  1.469E+04

Data Set Number =  11  Bulk Oil % =  3.0     02:18:14:26:48
TC No:     1      2      3      4      5      6      7      8
Temp :   3.56   3.61   3.55   3.51   3.75   3.44   3.80   3.39
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
 3.53    2.28     2.21    2.94   -1.72   -16.4
 Thetab  Htube        Qdp
 1.285   1.142E+04  1.467E+04

Data Set Number =  12  Bulk Oil % =  3.0     02:18:14:33:11
TC No:     1      2      3      4      5      6      7      8
Temp :   3.06   3.07   3.02   3.00   3.12   2.98   3.14   2.90
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
 3.01    2.43     2.11    3.43   -1.69   -17.1
 Thetab  Htube        Qdp
  .739   1.120E+04  8.283E+03

Data Set Number =  13  Bulk Oil % =  3.0     02:18:14:33:43
TC No:     1      2      3      4      5      6      7      8
Temp :   3.00   3.01   2.94   2.92   3.05   2.90   3.08   2.81
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
 2.94    2.36     2.05    3.41   -1.77   -17.2
 Thetab  Htube        Qdp
  .738   1.136E+04  8.386E+03

Data Set Number =  14  Bulk Oil % =  3.0     02:18:14:40:43
TC No:     1      2      3      4      5      6      7      8
Temp :   2.70   2.74   2.73   2.71   2.80   2.71   2.79   2.61
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump

 2.71    2.41     2.03    3.79   -1.75   -17.9
 Thetab  Htube        Qdp
  .488   1.078E+04  5.257E+03

Data Set Number =  15  Bulk Oil % =  3.0     02:18:14:41:19
TC No:     1      2      3      4      5      6      7      8
Temp :   2.66   2.70   2.65   2.67   2.74   2.66   2.71   2.54
 Twa     Tliqd    Tliqd2  Tvapr   Psat    Tsump
 2.65    2.39     2.00    3.78   -1.77   -18.0
 Thetab  Htube        Qdp
  .458   1.145E+04  5.244E+03
```

```
Month, date and time :05:06:11:47:44

NOTE: Program name : DRP4
      Disk number  = 10
      Old file name: GTB18S
      This data set taken on : 11:25:11:35:33
      Tube Number:   9

Data Set Number =   1  Bulk Oil % =  1.0      11:25:15:46:12
TC No:     1      2      3      4      5      6      7      8
Temp :   8.27   8.61   7.83   7.87   7.93   7.82   9.85   7.81
 Twa    Tliqd   Tliqd2  Tvapr  Psat    Tsump
 7.97   2.23    2.23    2.24  -1.73   -16.6
 Thetab  Htube       Qdp
 5.739  1.581E+04  9.073E+04

Data Set Number =   2  Bulk Oil % =  1.0      11:25:15:46:48
TC No:     1      2      3      4      5      6      7      8
Temp :   8.30   8.65   7.86   7.90   7.98   7.85   9.88   7.84
 Twa    Tliqd   Tliqd2  Tvapr  Psat    Tsump
 8.00   2.28    2.27    2.28  -1.68   -16.6
 Thetab  Htube       Qdp
 5.728  1.582E+04  9.062E+04

Data Set Number =   3  Bulk Oil % =  1.0      11:25:15:54:05
TC No:     1      2      3      4      5      6      7      8
Temp :   6.93   7.13   6.62   6.62   6.64   6.50   7.78   6.54
 Twa    Tliqd   Tliqd2  Tvapr  Psat    Tsump
 6.66   2.21    2.22    2.77  -1.75   -17.0
 Thetab  Htube       Qdp
 4.448  1.348E+04  5.995E+04

Data Set Number =   4  Bulk Oil % =  1.0      11:25:15:54:55
TC No:     1      2      3      4      5      6      7      8
Temp :   6.95   7.15   6.61   6.62   6.62   6.49   7.77   6.50
 Twa    Tliqd   Tliqd2  Tvapr  Psat    Tsump
 6.66   2.22    2.23    2.81  -1.74   -16.3
 Thetab  Htube       Qdp
 4.430  1.353E+04  5.993E+04

Data Set Number =   5  Bulk Oil % =  1.0      11:25:16:03:48
TC No:     1      2      3      4      5      6      7      8
Temp :   6.09   6.19   5.82   5.81   5.77   5.74   6.37   5.66
 Twa    Tliqd   Tliqd2  Tvapr  Psat    Tsump
 5.82   2.24    2.23    3.18  -1.73   -17.4
 Thetab  Htube       Qdp
 3.583  1.036E+04  3.712E+04

Data Set Number =   6  Bulk Oil % =  1.0      11:25:16:04:22
TC No:     1      2      3      4      5      6      7      8
Temp :   6.11   6.23   5.84   5.84   5.80   5.77   6.42   5.73
 Twa    Tliqd   Tliqd2  Tvapr  Psat    Tsump
 5.85   2.27    2.26    3.22  -1.69   -17.4
 Thetab  Htube       Qdp
 3.588  1.034E+04  3.712E+04

Data Set Number =   7  Bulk Oil % =  1.0      11:25:16:10:15
TC No:     1      2      3      4      5      6      7      8
Temp :   5.41   5.52   5.19   5.32   5.25   5.16   5.50   5.12
 Twa    Tliqd   Tliqd2  Tvapr  Psat    Tsump

 5.24   2.24    2.20    3.61  -1.74   -17.7
 Thetab  Htube       Qdp
 3.020  7.320E+03  2.211E+04

Data Set Number =   8  Bulk Oil % =  1.0      11:25:16:12:11
TC No:     1      2      3      4      5      6      7      8
Temp :   5.25   5.32   4.98   5.13   5.06   4.95   5.29   4.90
 Twa    Tliqd   Tliqd2  Tvapr  Psat    Tsump
 5.04   2.14    2.05    3.56  -1.88   -17.7
 Thetab  Htube       Qdp
 2.949  7.480E+03  2.206E+04

Data Set Number =   9  Bulk Oil % =  1.0      11:25:16:17:23
TC No:     1      2      3      4      5      6      7      8
Temp :   5.05   5.14   4.81   5.05   4.94   4.81   4.95   4.78
 Twa    Tliqd   Tliqd2  Tvapr  Psat    Tsump
 4.90   2.25    2.22    3.45  -1.73   -17.7
 Thetab  Htube       Qdp
 2.663  5.114E+03  1.362E+04

Data Set Number =  10  Bulk Oil % =  1.0      11:25:16:18:04
TC No:     1      2      3      4      5      6      7      8
Temp :   5.10   5.20   4.83   5.09   4.99   4.85   5.00   4.85
 Twa    Tliqd   Tliqd2  Tvapr  Psat    Tsump
 4.95   2.30    2.27    3.44  -1.67   -17.6
 Thetab  Htube       Qdp
 2.657  5.103E+03  1.356E+04
```

```
Data Set Number =  11  Bulk Oil % =  1.0     11:25:16:24:54
TC No:     1      2      3      4      5      6      7      8
Temp :   4.75   4.88   4.42   4.84   4.75   4.61   4.62   4.58
 Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump
  4.66   2.30     2.29    3.15  -1.66   -16.3
 Thetab  Htube        Qdp
  2.360  3.273E+03  7.725E+03

Data Set Number =  12  Bulk Oil % =  1.0     11:25:16:25:38
TC No:     1      2      3      4      5      6      7      8
Temp :   4.76   4.88   4.42   4.84   4.74   4.61   4.60   4.58
 Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump
  4.66   2.30     2.29    3.13  -1.66   -16.0
 Thetab  Htube        Qdp
  2.360  3.264E+03  7.702E+03

Data Set Number =  13  Bulk Oil % =  1.0     11:25:16:31:21
TC No:     1      2      3      4      5      6      7      8
Temp :   4.45   4.54   4.09   4.60   4.39   4.34   4.36   4.28
 Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump
  4.37   2.27     2.27    2.95  -1.69   -14.9
 Thetab  Htube        Qdp
  2.094  2.361E+03  4.944E+03

Data Set Number =  14  Bulk Oil % =  1.0     11:25:16:31:59
TC No:     1      2      3      4      5      6      7      8
Temp :   4.46   4.55   4.12   4.61   4.43   4.38   4.38   4.32
 Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump
  4.39   2.30     2.29    2.94  -1.66   -14.8
 Thetab  Htube        Qdp
  2.096  2.352E+03  4.931E+03

Data Set Number =  15  Bulk Oil % =  1.0     11:25:16:37:53
TC No:     1      2      3      4      5      6      7      8
Temp :   4.19   4.29   3.84   4.38   4.07   4.06   4.00   3.99
 Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump
  4.09   2.23     2.23    2.83  -1.73   -14.8
 Thetab  Htube        Qdp
  1.863  1.582E+03  2.946E+03

Data Set Number =  16  Bulk Oil % =  1.0     11:25:16:38:28
TC No:     1      2      3      4      5      6      7      8
Temp :   4.20   4.30   3.83   4.36   4.07   4.05   3.98   3.99
 Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump
  4.09   2.23     2.22    2.82  -1.74   -14.8
 Thetab  Htube        Qdp
  1.862  1.582E+03  2.946E+03

Data Set Number =  17  Bulk Oil % =  1.0     11:25:16:44:56
TC No:     1      2      3      4      5      6      7      8
Temp :   3.97   4.04   3.67   4.17   3.77   3.81   3.67   3.74
 Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump
  3.85   2.19     2.19    2.71  -1.78   -15.2
 Thetab  Htube        Qdp
  1.660  1.146E+03  1.901E+03

Data Set Number =  18  Bulk Oil % =  1.0     11:25:16:45:33
TC No:     1      2      3      4      5      6      7      8
Temp :   3.97   4.04   3.68   4.19   3.78   3.82   3.66   3.72
 Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump
  3.85   2.19     2.19    2.71  -1.77   -15.2
 Thetab  Htube        Qdp
  1.660  1.147E+03  1.904E+03

Data Set Number =  19  Bulk Oil % =  1.0     11:25:16:51:19
TC No:     1      2      3      4      5      6      7      8
Temp :   3.69   3.73   3.50   3.77   3.40   3.46   3.25   3.32
 Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump
  3.51   2.19     2.18    2.58  -1.78   -15.4
 Thetab  Htube        Qdp
  1.326  8.573E+02  1.137E+03

Data Set Number =  20  Bulk Oil % =  1.0     11:25:16:53:16
TC No:     1      2      3      4      5      6      7      8
Temp :   3.77   3.81   3.57   3.84   3.46   3.54   3.32   3.38
 Twa     Tliqd    Tliqd2  Tvapr  Psat    Tsump
  3.58   2.25     2.25    2.62  -1.71   -15.7
 Thetab  Htube        Qdp
  1.335  8.630E+02  1.152E+03
```

APPENDIX D

UNCERTAINTY ANALYSIS

The uncertainty of the heat-transfer coefficient at 60 kW/m^2 and 8 kW/m^2 for data runs of the GEWA-T tube (GTB185 with one percent oil concentration) and of the Thermoexcel-E (TXE222 with three percent oil concentration) are analyzed below. The method of analysis is based on Kline-McClintock [Ref. 20] method of uncertainty analysis.

The heat-transfer coefficient is:

$$h = (q_c)/(\overline{T}_{wo} - T_{SAT}) \qquad (D.1)$$

and

$$T_{wo} - T_{SAT} = T_{wi} - [Q_c \ln (D_2/D_1)]/(2 \pi k L) - T_{SAT} \qquad (D.2)$$

where

h = heat-transfer coefficient

q_c = heat flux corrected for end loss

$\overline{T}_{wo}$ = average outer tube wall temperature

T_{SAT} = saturation temperature

T_{wi} = average inner tube wall temperature

Q_c = heat input corrected for end losses

D_1 = tube internal diameter

D_2 = tube external diameter

k = tube wall thermal conductivity

L = length of tube's heated surface

To begin the analysis, a dummy variable is assigned to the conduction term as follows:

$$DELT = [Q_c \ln(D_2/D_1)]/(2\pi k L) \qquad (D.3)$$

In accordance with Kline and McClintock, the uncertainty of the heat-transfer coefficient is:

$$\frac{\delta h}{h} = \left[\left(\frac{\delta q_c}{q_c}\right)^2 + \left(\frac{\delta T_{WI}}{T_{WO} - T_{SAT}}\right)^2 + \left(\frac{\delta DELT}{T_{WO} - T_{SAT}}\right)^2 + \left(\frac{\delta T_{SAT}}{T_{WO} - T_{SAT}}\right)^2 \right]^{1/2} \qquad (D.4)$$

The uncertainty for the conduction term is estimated since the logarithmic error is negligible when compared to the other error of the analysis. The uncertainty of the conduction term is as follows:

$$\frac{\delta DELT}{DELT} = \left[\left(\frac{\delta Q_c}{Q_c}\right)^2 + \left(\frac{\delta k}{k}\right)^2 + \left(\frac{\delta L}{L}\right)^2 \right]^{1/2} \qquad (D.5)$$

where $Q_c = q_c \pi D_2 L$ (D.6)

The uncertainty of this term is as follows:

$$\frac{\delta Q_c}{Q_c} = \left[\left(\frac{\delta q_c}{q_c}\right)^2 + \left(\frac{\delta D_2}{D_2}\right)^2 + \left(\frac{\delta L}{L}\right)^2 \right]^{1/2} \qquad (D.7)$$

Table 4 contains a listing of the computed terms of equations D.1 through D.7 for selected data runs for the GEWA-T and the Thermoexcel-E tubes at specified heat-flux setting of 60 kW/m² and 8 kW/m². The algorithm in the data-

TABLE 4
UNCERTAINTY ANALYSIS

File Name	GTB185		TXE222	
Heat Flux	60 kW/m2	8 kW/m2	60 kW/m2	8 kW/m2
Oil %	1%	1%	3%	3%
$\frac{\delta Q_c}{Q_c}$	0.015	0.015	0.015	0.015
$\frac{\delta k}{k}$	0.03	0.03	0.03	0.03
$\frac{\delta L}{L}$	0.0025	0.0025	0.0025	0.0025
DELT	0.486	0.064	0.486	0.064
$\frac{\delta DELT}{DELT}$	0.069	0.520	0.069	0.526
T_{WI} (C)	6.845	4.678	6.904	2.964
T_{WI} (C)	0.49	0.065	0.49	0.065
T_{SAT} (C)	2.215	2.295	2.265	2.205
T_{SAT} (K)	0.1	0.1	0.1	0.1
$\frac{\delta T_{WI}}{\overline{T}_{WO}-T_{SAT}}$	0.111	0.028	0.111	0.088
$\frac{\delta DELT}{\overline{T}_{WO}-T_{SAT}}$	0.008	0.014	0.008	0.046
$\frac{\delta T_{SAT}}{\overline{T}_{WO}-T_{SAT}}$	0.023	0.042	0.023	0.135
$\frac{\delta q_c}{q_c}$	0.02	0.02	0.02	0.02
$\frac{\delta h}{h}$	0.115	0.056	0.115	0.169
$h(W/m^2\ K)$	13480	3273	14140	11200

reduction program used this approach and assumed that all the eight wall thermocouples were used to calculate the heat-transfer coefficient.

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